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MINUTES OF PROCEEDINGS
OF
THE INSTITUTION
OF
CIVIL ENGINEERS;

WITH OTHER
SELECTED AND ABSTRACTED PAPERS.

VOL. LXVIII.

EDITED BY
JAMES FORREST, Assoc. Inst. C.E., SECRETARY.



LONDON:
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ERRATA.

Vol. lv., p. 431. A bracket should be inserted in the second equation, which should read :—

$$E = N (A - B 1)$$

The third equation has the symbol I inserted instead of unity, both in the numerator and denominator. It should be :—

$$E = N A \left(\frac{1 - \frac{E_0 B}{A R}}{1 - \frac{N B}{R}} \right)$$

„ lxiii., p. 309, lines 36 and 37, for “all of which were executed under his charge and personal supervision,” read “Ill health compelled him to leave India for a time, before these works could be commenced ; but he acted as consulting engineer, and afterwards as agent in England, for the Calcutta municipality, who, on his departure, obtained from government the services of Mr. W. Smith, M. Inst. C.E., under whose charge and personal supervision the waterworks, with certain modifications in the original design, were constructed.”

„ lxvi., p. 371, second line of Table,

for	C ²	1982·88	2,445	1,867	1,373	712
read	C ²	278	248	254	204	240

„ „ p. 393, line 13 from bottom, for “ton” read “cask.”

„ „ p. 404, „ 5 „ „ “doloritic” read “doleritic.”

„ „ p. 430, footnote, for “Kemp” read “Kaemp.”

„ „ p. 456, last line, for “spongy platinum” read “spongy lead.”

„ lxvii., p. 234, line 29, for “Plate 8, Fig. 1,” read “Plate 7.”

„ „ „ „ 4 from bottom, for “Plate 8, Fig. 2,” read “Plate 7.”

„ „ p. 240, lines 34 and 35, for “Plate 8, Fig. 3,” read “Plate 7.”

„ „ p. 249, line 21, for “Plate 8, Fig. 3,” read “Plate 7.”

„ „ p. 532, Table III., fifth column, line 4, for ·000001 read ·000601.

„ lxviii., p. 38, line 10, for “Fig. 36” read “Fig. 35.”

„ „ p. 151, line 26, for “15½” read “13½.”

„ „ p. 165, lines 24 and 25, for “air compressors of 17-inches diameter and 2-feet length of stroke ; they take in about 41·1 cubic” read “air compressors of 18-inches diameter and 2-feet length of stroke ; they take in about 14·1 cubic.”

„ „ p. 255, lines 21 and 22, for “Tiddiman” read “Tiddeman.”

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1881-82.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

ANNUAL GENERAL MEETING.

20 December, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the Chair.

THE notice convening the meeting having been read,

Messrs. A. T. Atchison, R. W. P. Birch, W. A. Dawson, J. M. Dobson, C. Frewer, C. E. Hollingsworth, T. M. Smith, J. Thomson, and A. Williams were requested to act as Scrutineers of the Ballot for the election of the President, Vice-Presidents, and other Members of Council for the ensuing year; and it was resolved that the Ballot Papers should be sent for examination at intervals during the time the Ballot remained open.

The Ballot having been declared open, the Secretary read the Annual Report of the Council upon the proceedings of the Institution during the past year and upon its general condition. (*Vide* page 3.)

Resolved,—That the Report of the Council be received and approved, and that it be printed in the "Minutes of Proceedings" in the usual manner.

The Telford, Watt, and George Stephenson Medals, the Telford and Manby Premiums, and the Miller Prizes, which had been awarded, were presented. (*Vide* pages 16 and 17.)

Resolved,—That the thanks of the Institution are justly due and are presented to the Vice-Presidents and other Members of Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Brunlees, Vice-President, returned thanks.

[THE INST. C.E. VOL. LXVIII.]

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Abernethy, President, for his persevering endeavours in the interests of the Institution, for his unremitting attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Abernethy, President, returned thanks.

Resolved,—That the thanks of the Institution are due and are presented to Messrs. Charles Douglas Fox and Edward Easton, the Auditors appointed at the last Annual Meeting, for the time and trouble they have bestowed in verifying the Accounts; and that Messrs. Edward Easton and J. Clarke Hawkshaw be requested to act as Auditors for the ensuing year.

Mr. Charles Douglas Fox returned thanks.

Resolved,—That the cordial thanks of the Institution be tendered to Mr. Charles Manby, Honorary Secretary, and to Mr. James Forrest, the Secretary, for their long-continued and valued services.

The Scrutineers then announced that the following gentlemen had been duly elected :

President.

Sir W. G. ARMSTRONG, C.B., F.R.S.

Vice-Presidents.

James Brunlees, F.R.S.E.	|	Sir Frederick J. Bramwell, F.R.S.
Sir Joseph Wm. Bazalgette, C.B.	|	Edward Woods.

Other Members of Council.

Benjamin Baker.	|	William Pole, F.R.SS. L. & E.
George Berkley.	|	Robert Rawlinson, C.B.
George Barclay Bruce.	|	Alexander Meadows Rendel, M.A.
Sir John Coode.	|	Charles William Siemens, F.R.S.
Edward Alfred Cowper.	|	David Stevenson, F.R.S.E.
James Nicholas Douglass.	|	Sir W. Thomson, F.R.SS. L. & E.
Alfred Giles.	|	Sir Jos. Whitworth, Bart., F.R.S.
Harrison Hayter.	|	

Resolved,—That the thanks of the Meeting be given to Messrs. Atchison, Birch, Dawson, Dobson, Frewer, Hollingsworth, Smith, Thomson, and Williams, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

[ANNUAL REPORT.

ANNUAL REPORT.

THIS Meeting has been convened according to the Charter and By-Laws for two purposes ; one is to receive from the retiring Council, a Report upon the proceedings of the Institution during their period of office and upon its general condition ; the other is for the election by the members present of a Council for the ensuing year.

Respecting the latter purpose, it may be stated that, when the Council were engaged in arranging the balloting list, Mr. Abernethy, following the example of his immediate predecessor, intimated that he did not wish to serve a second year as President ; the senior Vice-President in duration of office, Sir W. G. Armstrong, has, therefore, been nominated, and Mr. Edward Woods has been selected to fill the vacancy thus created among the Vice-Presidents. The other Members of Council elected last December, (with the exception of Sir Charles Hartley who wishes to retire owing to his frequent and unavoidable absence from England during the session of the Institution), have been retained in the list, to which eleven other Members of the Institution, following distinct branches of engineering and resident in different parts of the kingdom, have been added, to make up the number demanded by the By-Laws.

A year's work has to be recorded this evening. It is the sixty-third annual meeting since the foundation of the Institution—a period very short in the world's history, but one during which great changes have been effected, and in which Civil Engineers have had a considerable share. Established to promote Mechanical Science, particularly in its application to Civil Engineering, it fell to the lot of Thomas Tredgold, then an Honorary Member, in 1828, at the request of the governing body, to define the nature and objects of the Art as at that time understood. This he did with far-seeing intelligence—in words which unfortunately were not all embodied in the Charter—but in which he pointed out that the domain of the Civil Engineer would extend with every discovery of Science.

Having regard to the great and increasing number of subjects which occupy the attention of the Engineer, it is manifestly important that the Papers read at the meetings of the Institution and selected for publication should be so varied as to be useful to its members in whatever branch of the profession they may be engaged. The tendency of modern manufacturing processes is to rely more and more upon machinery, the design and construction of which, as it becomes more elaborate, can no longer be the work of the mere handicraftsman, but calls forth the highest powers of

the skilled engineer. It thus happens that men are now to be found exercising engineering vocations widely different from those of the designers of roads, bridges, and other similar public works, who, very erroneously, have often alone been recognised as Civil Engineers. As the Institution is largely composed of the former class of Engineer, it is necessary that the range of subjects for Papers should be widened, in order that all interests may be consulted. A comparison of the Papers contributed thirty years ago with those of the present day is both interesting and instructive : it shows the great change brought about in the interval in the practice of the profession. New terms have been devised to meet the requirements arising from new industrial applications of science, in such works as the development of electricity as a motive and as a lighting agent, and also in chemical processes. The Council can appeal to the Minutes of Proceedings issued since the last Annual Meeting as evidence of the success that has been attained in this direction.

It may be appropriate to give a short synopsis of the contents of the four volumes. The first Paper by Mr. Benjamin Walker, described machinery used in steel-making on a large scale, as distinct from the pot or crucible process. In the discussion it was suggested that the Author had confined himself to his own practice. But the objection, which is a general one where Papers of this class are concerned, loses its force when it is considered that if every possible contributor were to wait until he had acquired a knowledge of all the technical processes of his fellow manufacturers before sending in a communication, much valuable information would never be made public. The next Papers read were on the New Zealand and the Ceylon railways, by Messrs. J. P. Maxwell and J. R. Mosse respectively. They were chiefly valuable as affording a basis, from executed works, for comparing two distinct methods of attaining the same end (overcoming steep mountain ranges) i.e. by long and winding gradients of moderate inclination, or by direct lines worked by engines of special type. The general opinion seemed to be that neither system could be pronounced absolutely the better, though it was evident that mechanical expedients for surmounting steep gradients were being regarded with increased favour. A French engineer, Mr. T. Seyrig, a Member of the Institution, contributed a Paper on the different modes of erecting iron bridges, which elicited a long and interesting discussion, the whole forming a convenient epitome of examples of various systems, that will be most useful for reference. These three communications, supplemented by the report of the Annual General Meeting, by seven short Selected Papers, and by the usual quota of Foreign Abstracts, formed the first part, a volume of 466 pages.

Part II. for the session contained Mr. Abernethy's presidential address, relating mainly to the remarkable growth of dock and harbour accommodation for the commercial marine during the last thirty years. It was followed by Messrs. Brown and Adams's description of the winning of coal at Harris's Navigation pit, one of the deepest shafts in the kingdom. This Paper may be regarded as a model of excellent description, and it was accompanied by appendices of much interest to colliery engineers. The discussion was unusually animated, and of a character to support and sanction the view taken by the Council of late years of the value of promoting full debate on a limited number of important subjects, rather than contracting the discussions, in order to allow of more Papers being read. Then came a full and complete record of the Portsmouth Dockyard Extension works, and of the temporary plant (of a very costly and elaborate nature) employed in their construction, the first by Mr. C. Colson, and the second by Mr. C. H. Meyer. The principal feature of these works was the large use of concrete; while the second of the Papers contained an extremely clear account of the well-devised plant by which the works were carried out. The criticism evoked was mainly directed to the question of cost, the thoroughness and enduring character of the work being fully recognised. Mr. Max am Ende's Paper on the Weight and Limiting Dimensions of Girder Bridges was a theoretical disquisition on the best means of proportioning the material, so as to admit of the longest spans. The calculations were given for a hypothetical bridge, based upon a new formula for the weight of a girder with a parabolic upper boom, the Author advocating greater depth than usual. The subject is one of peculiar interest at the present moment, and the Author had no reason to complain of the reception given to his contribution. Eight short Selected Papers, mostly descriptive of special works or appliances, with the memoirs of deceased members and the Foreign Abstracts, completed this volume.

The succeeding volume was more varied in character. In it was included Sir William Thomson's memoir on Tidal Recording Instruments, which opened out a wide field for inquiry into the rationale of these important adjuncts to modern hydraulic engineering. Owing to the Author being one of their colleagues, the Council are restricted to the expression of their sense of the value of Sir William's highly philosophical essay. Mr. David Phillips followed with a Paper on the Corrosion of Iron and Steel, giving the results of numerous experiments intended to show that mild steel is more susceptible to corrosive influences than wrought iron, but in the discussion a contrary view was generally entertained.

Mr. Benjamin Baker's memoir on the Actual Lateral Pressure of Earthwork was a record of observations on the behaviour of walls and other similar retaining structures under various conditions. The special feature of the Paper was that, whereas previous research in this direction has mostly taken the form of mathematical investigation or of experiment upon models, Mr. Baker's deductions were made chiefly from actual works, the conclusion arrived at being that the usual formula generally over-estimated the actual pressure of earthwork. The discussion was enriched by written contributions from several eminent foreign engineers, who maintained that Mr. Baker's examples were, as far as could be expected, in accordance with the most recent and approved theory of the equilibrium of earthwork. In this issue of the Proceedings there were no less than ten Selected Papers, the volume containing nearly 500 pages and 8 plates.

Part IV. also formed a bulky volume. The first Paper was by Mr. W. R. Browne, "On the Relative Value of Tidal and Upland Waters in Maintaining Rivers, Estuaries, and Harbours." Here the Author boldly contested the correctness of the generally received opinion as to the value of tidal water, and argued, from examples which he cited, that it would, as a rule, be advantageous when practicable to exclude the tide from navigable rivers. In the discussion these views were vigorously assailed; nevertheless the sustained interest of the debate showed that the Council were fully warranted in allowing the Author an opportunity of explaining his views. Mr. J. I. Thornycroft next furnished an account of the modern Torpedo-boat and High-speed Steam Yacht, with the development of which his name is so honourably associated. The cordial reception of this Paper indicated the sense entertained of Mr. Thornycroft's successful efforts in an entirely new branch of marine construction, and in largely reducing the weight of motive power for steam navigation. The last Paper of the session, by Mr. R. H. Brunton, described the production of Paraffin and Paraffin Oils by the destructive distillation of shales. The various stages of manufacture afforded as much scope for engineering science and talent as were exemplified in the preparation of illuminating gas, to which the processes were analogous. Twelve Selected Papers relating to various questions of interest to engineers were inserted in this volume, which volume also contained the usual amount of matter from foreign sources.

From this brief enumeration it will be noticed that, besides the President's Address, fourteen Papers have been read and discussed, while thirty-seven other communications were selected for printing, six of this number having been read at Supplemental Meetings of

Students. The combined articles ranged over most of the questions now occupying the attention of engineers. The Foreign Abstracts continue to be highly appreciated, especially by those members in distant countries who are debarred from access to information respecting the progress of engineering on the Continent and in America.

The Council have had the pleasure to award, for Papers included in the Proceedings for the past session, George Stephenson Medals and Telford Premiums to Thomas Forster Brown, George Frederick Adams and Benjamin Baker;¹ a Watt Medal and a Telford Premium to John Isaac Thornycroft; Telford Medals and Telford Premiums to Theophilus Seyrig, Max am Ende, and Dr. James Weyrauch; Telford Premiums to Richard Henry Brunton,² Charles Colson,² Christian Hendrick Meyer, Benjamin Walker, James Richard Bell, John Lewis Felix Target,³ and William Thomas Henney Carrington; and the Manby Premium to Joseph Prime Maxwell.

The Council are glad to report that a Subject-matter Index to the whole of the publications, from 1837 to 1879 inclusive, has been completed and circulated. The issue of this work may be said to mark an epoch in Engineering literature. The approval with which it has been received may be taken as evidence that the unobtrusive but painstaking and conscientious labour of the compilers has been appreciated by those most capable to judge of its value. A Name Index, which will be a complement to the other, is in course of preparation, and will be ready during the ensuing year.

In the course of the spring a letter was received from Messrs. J. S. and A. B. Wyon, medallists, to the effect that they had engraved dies, adapted for a prize medal, having for the obverse a portrait of George Stephenson, and for the reverse a representation of one of the earliest locomotives built by him. These dies were purchased by the Council, and have been used in preparing the George Stephenson Medals, now for the first time awarded.

Of eighteen Papers received from Students, thirteen were read at Meetings held on as many consecutive Friday evenings, commencing on the 4th of February. The chair on these occasions was once occupied by the President, twice by Past-Presidents, and at other times generally by one of the Vice-Presidents or by a Member of Council. Although no one of the Papers was considered to be of a sufficiently high standard for a Miller Scholar-

¹ Has previously received a Telford Medal and a Telford Premium.

² Have previously received Telford Premiums.

ship, nine were judged worthy of Miller Prizes, and six of these have been printed as Selected Papers in the Minutes of Proceedings.

Miller Prizes have been bestowed upon James Bernard Hunter, Mathew Buchan Jamieson, Thomas Stewart, William Henry Edinger, Daniel Macalister, Lindsay Burnet, Edward Walter Nealor Wood, Arthur Stuart Vowell, and William Marriott. Mr. Burnet received a similar prize in a previous session.

The Library continues to increase so rapidly that it will soon become difficult to find any available wall-space to meet future additions. This growth is due not only to the many serial works comprised in the collection, but also to all important publications of Engineering interest being acquired as they appear. During the current year many purchases have been made, and numerous presents have been received from foreign governments, as well as from individuals. In some instances such gifts had a special value as the works so presented could not have been procured through the ordinary channels of trade. Although the complete display of the books on the shelves is curtailed through want of space, all are immediately available for reference through the medium of the Catalogue, which is kept up to date.

According to a Table which is subjoined,¹ there has been

¹ The following Table shows the changes that have occurred in the several classes belonging to the Institution, irrespective of the Students, during the last two Sessions :

—	Nov. 30, 1879, to Nov. 30, 1880.					Nov. 30, 1880, to Nov. 30, 1881.				
	Honorary Members.	Members.	Associate Members.	Associates.	Totals.	Honorary Members.	Members.	Associate Members.	Associates.	Totals.
Members at commencement . . .	17	1,140	1,221	582	2,960	18	1,209	1,287	568	3,082
Transferred to Members	..	..	44	2		..	..	30	2	
Do. to Associate Members . . .	..	..	..	6		..	..	..	1	
Elections . . .	2	43	129	15		..	47	183	7	
Restored to Register . . .	..	..	..	1	190	..	1	..	2	240
Deaths . . .	1	15	13	9		..	24	24	12	
Resignations . . .	..	5	3	8	-68	..	2	5	8	-85
Erased . . .	..	..	9	5	122	..	2	6	2	155
Numbers at termination	18	1,209	1,287	568	3,082	18	1,261	1,406	552	3,237

during the past twelve months an increase of 52 Members and of 119 Associate Members, with a decrease of 16 Associates, showing a net effective addition (the Honorary Members remaining the same) of 155, or at the rate of 5 per cent. The gross number on the books, without counting the Students, on the 30th of November last was 3,237, thus distributed, viz., 18 Honorary Members, 1,261 Members, 1,406 Associate Members, and 552 Associates.

The deceases during the year have been at the rate of nearly 19 per 1,000, and have included several very old Members, notably Mr. James Ashwell, one of the five founders of the Institution. The following is the list:—

Members: Benedict Albano; James Ashwell, M.A. (lxvi. 372); Charles Bernard Baker (lxv. 364); William Brunton (lxvii. 395); William Alexander Brunton (lxiv. 338); Francis Charlton (lxvi. 375); José Manuel Farfan de los Godos (lxv. 364); Frank Fitzjames (lxvii. 396); John Fraser; William Bancks Hall (lxv. 366); Francis Hawkes; John Head (lxvii. 397); Dr. Manoel Buarque de Macedo; Robert Mallet, M.A., F.R.S.; Alfred William Morant (lxvi. 377); William Milnor Roberts; James Samuel Statter (lxv. 367); Andrew Stein; John Taylor; John Furness Tone (lxvii. 399); Richard James Ward (lxv. 370); Baron Max Maria von Weber (lxv. 371); John Wright; and Oswald Younghusband (lxiv. 339).

Associate Members: James Grey Adamson (lxvii. 403); Thomas James Bailey (lxvi. 379); Thomas Bevington; Richard Broome; Joseph Green Cooke (lxvi. 380); Charles Davies; Rowland Lyttleton Archer Davies; Joseph Francis Delany (lxv. 375); William Exall (lxvii. 405); William Coulthurst Gibbons (lxvi. 382); William Scott Henderson; Philip Harrison Holmes; William Humber (lxv. 375); John Milton Lewis; Lauchlan Alexander Entwistle Mackinnon (lxv. 377); William John Maxwell (lxvi. 384); George Brooke Muriel (lxv. 377); Alexander Manson Rymer-Jones (lxvii. 407); John Slate (lxvii. 408); James John Stevens; Thomas Lanfear Tanner (lxvii. 410); Hamilton Ela Towle (lxvii. 411); James Jenkin Trathan (lxv. 378); John Hamilton Wicksteed (lxvii. 413); and Edward Bentinck Williams (lxvii. 415).

Associates: John David Barry (lxv. 380); Henry Heather Bigg; John Collier; Peter Lindsay Henderson (lxiv. 341); Capt. William Henry Johnstone, R.E. (lxvii. 415); John Joicey; Thomas Lambert; William Owen (lxiii. 333); Angier March Perkins (lxvii. 417); Robert Francis Reed; Edward Antoine Sacré (lxvii. 419); and William Joshua Trehearne.

The resignations accepted have been :—

Members: Edward Lawrence Ireland Blyth; and Thomas Mercer Vigors.

Associate Members: Alfred Dowson; Charles Flood; John Henry Holland; John Motley Smith; and Samuel Robert Wilkes, B.A.

Associates: Frederick Augustus Abel, C.B., F.R.S.; Thomas Denville Barry; Rowland Brotherhood; Maj. Henry Doveton, R.E.; Capt. John Barker Lindsell; Lieut.-Col. Edward Talbot Thackeray, *U.C.*, R.E.; Charles Brown Trollope; and Edmund Wormald.

The number of Students now attached to the Institution is 662, an increase in the year of 49. During the past session 54 Students were elected Associate Members. As, since the creation of the class, 1,462 candidates have been admitted, a balance of 800 has to be accounted for. Of that number about one half have been elected into the Corporation, while the other half have ceased to belong to the Institution, and in most instances to the profession.

The Council have had under consideration the By-Laws as to the admission of Students. It has been suggested that only those candidates should be accepted who have received a suitable preliminary education; to be shown, either by their having passed certain prescribed examinations at recognised collegiate institutions, to be approved from time to time; or else, by presenting themselves for examination by examiners to be appointed by the Council, and passing such examinations satisfactorily. Pending a decision on this point candidates are now required to furnish satisfactory evidence that they are by education qualified to enjoy the privileges they seek.

The statement of Accounts, verified and certified by Mr. Charles Douglas Fox and Mr. Edward Easton, the Auditors appointed at the last Annual General Meeting, shows that the receipts have been £15,906 10s. 11d., including £12,398 11s. 5d. assigned to income, £3,076 14s. to capital (being admission fees and life compositions), and £431 5s. 6d. to dividends on trust funds. The payments amounted to £12,092 7s. 11d.—more than one half being debited to “Minutes of Proceedings” and to the Subject-Index—while a sum of £3,000 was invested, partly in New Three per cents., and partly in Midland Railway Four per cent. Debenture Stock, and a sum of £390 0s. 1d. was expended for Premiums and Prizes under Trust. The cash balance in hand is £771 12s. 1d., being £424 2s. 11d. above what it was at the same period in 1880. The income was nearly 4 per cent., and the total receipts 6 per cent., in excess of the previous year.

The nominal or par value of the investments belonging absolutely to the Corporation is £36,838 11s. 8d., and of those held under trust £14,642 13s. 10d. The dividends on the former contributed £1,433 17s. 6d. to income, and were at the rate of nearly 4 per cent. per annum on the capital.

The progress of the Institution, in numbers and in means, may be well shown by the recital of a few facts. In December, 1853, the total income was estimated at £1,923, and the expenditure (exclusive of the cost of the "Minutes of Proceedings") at £1,649; whereas the actual income last year (without reckoning receipts on capital account and from trust funds) was £12,398 11s. 5d., and out of that income a sum of £6,523 17s. 8d. was expended on the publications. Again, on the 30th of November, 1862, the number of members of all classes was exactly 1,000 against 3,237 at the same date this year. But this does not represent the total growth of the Society, for fourteen years ago a class of Students was created, of whom there are now 662, so that there are on the lists 3,899 persons. Further, on the 30th of November, 1867, the Institution investments (irrespective of trust moneys) amounted to £17,133 1s. 3d.; in the next two years a sum of £18,120 2s. 4d. was paid for rebuilding and furnishing the enlarged premises, without the necessity for calling upon individual members for special subscriptions; and during the past twelve years the entrance fees and life compositions—which are rigidly treated as capital, and are not used for defraying ordinary expenses—have steadily accumulated, and are now of the nominal value, as before stated, of £36,838 11s. 8d. Moreover, at the commencement of the period in question the issue of the "Minutes of Proceedings" was much in arrear; and indeed it was only at the Annual General Meeting in December, 1866, that the Council were able to announce the completion of the series to that date. Since then the volumes, at first increased to two and later to four annually, have been regularly distributed, and what is equally important, have been paid for out of the income of the particular years to which they relate.

ABSTRACT of RECEIPTS and EXPENDITURE

RECEIPTS.				£. s. d.		
Dr.						
To balance in the hands of the Treasurer	317	9	7			
" " Secretary	29	19	7			
				347	9	2
INCOME.				£. s. d.		
— Subscriptions:—						
Arrears	355	9	6			
Current	10,164	13	6			
Advance	95	0	6			
— Library Fund	197	18	0			
— Minutes of Proceedings:—Repayment for Binding, &c.	151	12	5			
— Dividends: 1 year on						
	£.	s.	d.	<i>Institution Investments.</i>		
4,750 0 0	Great Eastern Railway Four per			185	5	1
	Cent. Debenture Stock					
3,000 0 0	London and North Western			117	2	6
	Ditto					
1,500 0 0	London, Brighton, and South			58	11	3
	Coast Ditto					
3,000 0 0	North Eastern Ditto			117	0	0
3,000 0 0	Great Northern Ditto			117	2	6
3,000 0 0	Lancashire and Yorkshire Ditto			117	0	0
3,000 0 0	Great Western Ditto			117	2	6
3,000 0 0	Caledonian Ditto			117	5	0
1,000 0 0	Midland Ditto			39	0	0
3,000 0 0	Highland Ditto			117	5	0
1,500 0 0	London, Brighton, and South					
	Coast Railway Four and a			65	17	8
	Half per Cent. Ditto					
3,000 0 0	Manchester, Sheffield, and Lin-			131	12	6
	colnshire Ditto					
2,088 11 8	New Three per Cents.			61	4	6
	6 months on					
2,000 0 0	Midland Railway Four per Cent.)			39	3	4
	Debenture Stock					
<u>£36,838 11 8</u>	Total nominal or par value.					
— Interest on Deposit Account	33	5	8	12,398	11	5
CAPITAL.						
— Admission Fees	2,579	17	0			
— Life Compositions	496	17	0			
				3,076	14	0
Carried forward				£15,822	14	7

from the 1st DEC., 1880, to the 30th NOV., 1881.

PAYMENTS.

Cr.	£.	s.	d.
GENERAL EXPENDITURE.			
By House and Establishment Charges:—	£.	s.	d.
Repairs	99	1	11
New Building	289	7	6
Rent	666	8	4
Rates and Taxes	307	3	1
Insurance	41	16	6
Fixtures and Furniture	23	11	6
Lighting and Warming	112	12	9
Tea, Coffee, &c.	57	10	5
Assistance at Meetings	33	5	6
Household Expenses	108	19	5
			<u>1,689 16 11</u>
— Salaries	1,700	0	0
— Clerks, Messengers, and Housekeeper	652	10	10
— Donation to late Housekeeper	30	0	0
			<u>2,382 10 10</u>
— Postage, Telegrams, and Parcels	191	6	0
— Stationery and Printing	616	17	5
— Watt Medals	2	7	6
— Purchase of George Stephenson Dies	105	0	0
— Diplomas	40	19	4
— Annual Dinner (Official Invitations, &c.)	161	19	6
			<u>1,118 9 9</u>
— Library:—			
Books	232	7	2
Periodicals	31	5	11
Binding	109	12	8
Maps	4	7	0
			<u>377 12 9</u>
— Publication:—			
“Minutes of Proceedings”	5,702	17	11
“Subject-matter Index” Vol. I. to Vol. LVIII.	820	19	9
			<u>6,523 17 8</u>
			<u>12,092 7 11</u>

CAPITAL INVESTMENTS.

— £744 10 New Three per Centa	736	2	6
— £2,000 Midland Railway Four per Cent. Debenture Stock	2,263	17	6
			<u>3,000 0 0</u>
Carried forward	£15,092	7	11

ABSTRACT of RECEIPTS and EXPENDITURE

RECEIPTS—continued.														
Dr.						£.	s.	d.	£.	s.	d.			
	Brought forward . .								15,822	14	7			
TRUST FUNDS.														
To Dividends: 1 year on														
£.	s.	d.	Telford Fund.											
2,839	10	10	Three per Cent. Consols . .			83	1	2						
2,586	0	11	Three per Cent. Reduced . .			75	15	11						
2,377	10	5	Three per Cent. Consols (Unex- pended Dividends . . }			69	10	11						
913	2	7	Three per Cent. Reduced Ditto . .			26	15	7						
<hr/>														
8,716	4	9	Total nominal or par value.											
<hr/>														
Manby Donation.														
250	0	0	Great Eastern Railway Four per Cent. Debenture Stock . . }			9	15	2						
<hr/>														
Miller Fund.														
3,125	0	0	New Three per Cents. . . .			91	12	0						
643	19	8	Three per Cent. Consols, Unex- pended Dividends . . }			18	16	7						
1,355	14	11	Three per Cent. Reduced, Ditto . .			39	14	8						
<hr/>														
5,124	14	7	Total nominal or par value.											
<hr/>														
Howard Bequest.														
551	14	6	New Three per Cents. . . .			16	3	6						
<hr/>								431			5	6		
								<hr/>			£16,254		0	1
											<hr/>			
SUMMARY OF INVESTMENTS.														
INSTITUTION INVESTMENTS										36,838		11	8	
TRUST FUNDS—														
Telford Fund			8,716			4	9							
Manby Donation			250			0	0							
Miller Fund			5,124			14	7							
Howard Bequest			551			14	6							
			<hr/>			14,642			13	10				
						<hr/>								
			Total nominal or par value			£51,481			5	6				

from the 1st DEC., 1880, to the 30th NOV., 1881.

Cr.		PAYMENTS—continued.		£.		s.		d.		£.		s.		d.	
		Brought forward . .								15,092		7		11	
		TRUST FUNDS.													
By Telford Premiums				256		0		8							
— Manby Premium				10		10		6							
— Miller Scholarships				80		0		0							
— Miller Prizes				48		9		4							
										390		0		1	
												15,482		8 0	
— Balance Nov. 30, 1881, viz. :—															
Cash in the hands of the Treasurer				750		7		11							
" " Secretary				21		4		2							
										771		12		1	
		</													

PREMIUMS AWARDED.

SESSION 1880-81.

THE COUNCIL of The Institution of Civil Engineers have awarded the following Premiums :

FOR PAPERS READ AT THE ORDINARY MEETINGS.

1. George Stephenson Medals, and Telford Premiums, to Thomas Forster Brown and George Frederick Adams, MM. Inst. C.E., for their Paper on "Deep Winning of Coal in South Wales."
 2. A Watt Medal and a Telford Premium, to John Isaac Thornycroft, M. Inst. C.E., for his Paper "On Torpedo-Boats and Light Yachts for High Speed Steam Navigation."
 3. A Telford Medal, and a Telford Premium, to Theophilus Seyrig, M. Inst. C.E., for his Paper on "The Different Modes of erecting Iron Bridges."
 4. A Telford Medal, and a Telford Premium, to Max am Ende, Assoc. M. Inst. C.E., for his Paper "On the Weight and Limiting Dimensions of Girder Bridges."
 5. A George Stephenson Medal, and a Telford Premium, to Benjamin Baker,¹ M. Inst. C.E., for his Paper on "The Actual Lateral Pressure of Earthwork."
 6. A Telford Premium, to Richard Henry Brunton,² M. Inst. C.E., for his Paper on "The Production of Paraffin and Paraffin Oils."
 7. A Telford Premium, to Charles Colson,² Assoc. M. Inst. C.E., for his Paper on "Portsmouth Dockyard Extension Works."
 8. A Telford Premium, to Christian Hendrick Meyer, Assoc. M. Inst. C.E., for his Paper on the "Temporary Works and Plant at the Portsmouth Dockyard Extension."
 9. A Telford Premium, to Benjamin Walker, M. Inst. C.E., for his paper on "Machinery for Steel-making by the Bessemer and the Siemens Processes."
 10. The Manby Premium, to Joseph Prime Maxwell, Assoc. M. Inst. C.E., for his Paper on "New Zealand Government Railways."
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¹ Has previously received a Telford Medal and a Telford Premium.

² Have previously received Telford Premiums.

FOR PAPERS PRINTED IN THE PROCEEDINGS WITHOUT BEING
DISCUSSED.

1. A Telford Medal, and a Telford Premium, to Dr. J. Weyrauch, for his Paper "On the Calculation of Dimensions as depending on the Ultimate Working Strength of Materials."
2. A Telford Premium, to James Richard Bell, M. Inst. C.E., for his Paper on "The Empress Bridge over the Sutlej."
3. A Telford Premium, to John Lewis Felix Target,¹ M. Inst. C.E., for his Paper "Experiments on a New Form of Module for Irrigation Purposes."
4. A Telford Premium, to William Thomas Henney Carrington, Assoc. M. Inst. C.E., for his Paper on "Three Systems of Wire-Rope Transport."

FOR PAPERS READ AT THE SUPPLEMENTAL MEETINGS OF STUDENTS.

1. A Miller Prize, to James Bernard Hunter, Stud. Inst. C.E., for his Paper on "Wood-working Machinery as applied to the Manufacture of Railway-Carriages and Wagons."
2. A Miller Prize, to Mathew Buchan Jamieson, Stud. Inst. C.E., for his Paper on "The Internal Corrosion of Cast-Iron Pipes."
3. A Miller Prize, to Thomas Stewart, Stud. Inst. C.E., for his Paper on "The Prevention of Waste of Water."
4. A Miller Prize, to William Henry Edinger, Stud. Inst. C.E., for his Paper on "Brick-and-Concrete and Concrete Gas-holder Tanks."
5. A Miller Prize, to Daniel Macalister, Stud. Inst. C.E., for his Paper on "Caissons for Dock Entrances."
6. A Miller Prize, to Lindsay Burnet,² Stud. Inst. C.E., for his "Description of a Cargo-carrying Coasting Steam-Ship, with detailed investigation as to its efficiency."
7. A Miller Prize, to Edward Walter Nealer Wood, Stud. Inst. C.E., for his Paper on "The Improvement of the Old Harbour at Holyhead."
8. A Miller Prize, to Arthur Stuart Vowell, Stud. Inst. C.E., for his Paper on "Steel; its chemical constitution and behaviour under tensile strain."
9. A Miller Prize, to William Marriott, Stud. Inst. C.E., for his Paper on "Boilers."

¹ Has previously received a Telford Premium.

² Has previously received a Miller prize.

* * Of the nine Students' Papers last enumerated, the first six have been printed in the Minutes of Proceedings.

SUBJECTS FOR PAPERS.

SESSION 1881-82.

THE COUNCIL of The Institution of Civil Engineers invite communications, of a complete and comprehensive character, on any of the Subjects included in the following list, as well as on other analogous questions. For approved Original Communications, the Council will award Premiums, arising out of Special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The TELFORD FUND, left “in trust, the Interest to be expended in Annual Premiums, under the direction of the Council.” This bequest (with accumulations of dividends) produces £260 annually.

2. The MANBY DONATION, of the value of about £10 a year, given “to form a Fund for an Annual Premium or Premiums for Papers read at the meetings.”

3. The MILLER FUND, bequeathed by the testator “for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the ‘Telford Fund.’” This Fund (with accumulations of dividends) realises £160 per annum. Out of this Fund the Council have established a Scholarship,—called “The Miller Scholarship of The Institution of Civil Engineers,”—and are prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years.

4. The HOWARD BEQUEST, directed by the testator to be applied “for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron, or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution.” The annual income amounts to rather more than £16. It has been arranged to award this prize every five years, commencing from 1877. The next award will therefore be made in 1882.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the Premiums no distinction will be made between essays received from any one connected with the Institution (except in the cases of the Miller and the Howard bequests, which are limited by the donors), or from any other person, whether a Native or a Foreigner.

LIST.

1. The adoption of a Standard Test-piece for bars and plates.
2. The Mechanical and other Properties of Iron and Steel ; and the effect produced by tempering steel in oil and in water, with a description of the testing machinery.
3. The Behaviour of Iron and Steel under ordinary loads, and up to the limit of elasticity.
4. The methods of protecting Metal-work exposed to Corrosion, with examples.
5. The modern practice of Bridge-building in Germany, especially with reference to the details of construction and the substitution of bar and angle iron for wide flange-plates.
6. The Action of High Winds on lofty and exposed structures, and the best methods for determining the force of the wind.
7. The Comparative Cost of Transport by land and by water.
8. The Works carried out on the Continent of Europe and in North America for the Improvement of Rivers, and of Inland Navigation generally.
9. The methods used for determining the Discharge of Rivers, with a description of the Floats and Current-Meters employed for the purpose.
10. River Conservancy :—including a description of the physical conditions of the district, and the cause, effect, and means of prevention of Floods.
11. The Location and Construction of the most difficult portions of the several Pacific Railroads.
12. The Elevated Street Railroads of New York.

13. Continuous Railway Brakes.
14. Mechanical Power on Tramways, including steam, compressed air, electricity, &c.
15. A Review of recent Hydraulic Experiments.
16. Investigation as to the Quantity of Water yielded by Chalk Formation.
17. The Analysis of Water for Potable Purposes, having special reference to the method of estimating "Previous Sew Contamination."
18. The Design and Construction of Covered Service-Reservoirs for Town Water-Supply.
19. The Sewering of Towns on the separate system, by the exclusion of the surface waters.
20. The Utilisation of the Mechanical Power of the Tide and the current of rivers.
21. The type of Steam-Engine best adapted for ordinary factory purposes, in respect to economy in first cost, and in cost of maintenance, as well as in the use of steam.
22. The best method of Testing Steam-Engines (independent of their boilers), having regard to accuracy of the results, and ease with which the tests can be carried out.
23. The modern practice in the design and construction of Boilers.
24. On Magneto-electric and Dynamo-electric Machines, with their relative advantages.
25. The Generation, Storage, and Transmission of Electric Energy: the purposes to which it may be applied, and the source of loss.
26. The methods and appliances for Storing, Weighing, and Conveying Grain in and from Granaries.
27. The various systems of Grinding Wheat, and the Machinery used in Corn-Mills.
28. The different systems of Refrigerating Machinery, and the appliances for the preservation and transport of provisions.
29. The Utilisation of Waste Products in different manufacturing processes.

30. The Methods and Machinery employed for separating the impurities from coal as carried out in South Wales, in connection with the manufacture of coke for the iron and steel trades.
31. The application of Hydraulic Power to Machine Tools.
32. Drilling and Riveting Machinery for Girder work.
33. The different systems of Lifts in use in Warehouses and in Dwellings.
34. The latest development of the Compound Marine-Engine.
35. The special Construction of Vessels for the reception of Railway-Trains on Deck, indicating the arrangements for the shipping of such trains on their own wheels at various states of the tide.
36. The Methods and Machinery employed in Sinking and in Working deep Coal-Mines.
37. Coal-Depôts for Ocean Steamers, the various points involved in their management, and the preservation of the coal from deterioration.
38. The Methods employed in securing large and irregular-shaped mineral workings, for example—the Almaden Mines, the Great Comstock Lode, &c.
39. The Manufacture of Lead and the Extraction of Silver.
40. Instruments for measuring the Velocities of Vehicles, of Prime Movers, and of Wind- and Water-Meters.
41. The Distribution of Heat over large areas from a central source of supply.
42. The Methods and Appliances for Blasting Rock under Water.
43. The Management of Underground Waters in mining districts, and the relative economy of distributed or trunk pumping engines, adits, &c., in particular cases.
44. On proportioning Mains for the distribution of Water and of Gas.
45. Forces and Strains of Recoil considered with reference to the Elastic Field Gun-Carriage.

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

The Essays should be written in the third person, and be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract not exceeding 1500 words in length.

Illustrations, when necessary, should be drawn on tracing paper, to as small a scale as is consistent with distinctness, and ready to be engraved. When an illustrated communication is accepted for reading, a series of Diagrams will be required sufficiently large and boldly coloured to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted in competition for the Premiums.

The Communications must be forwarded to the Secretary of the Institution, from whom any further information may be obtained. There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it is dealt with in the succeeding one.

CHARLES MANBY, *Honorary Secretary.*

JAMES FORREST, *Secretary.*

THE INSTITUTION OF CIVIL ENGINEERS,

25, Great George Street, Westminster, London, S.W.

October, 1881.

EXCERPT BY-LAWS, SECTION XV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereinbefore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

NOTICE.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution as a body must not be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN DECEMBER 1, 1880, AND NOVEMBER 30, 1881.

AUTHORS.

- Airy, Sir G. B. No. 1,796.—Logarithms of the Values of all Vulgar Fractions, with Numerator and Denominator not exceeding 100, arranged in Order of Magnitude. (Vol. lxv., p. 271.)
- Allan, T. A. No. 1,819.—On Mines and Mining in the South of Spain. With 2 Maps and 2 Drawings.
- Allen, A. No. 1,775.—The Skidding of Railway Wheels. With 1 Drawing.
- Andrews, C. No. 1,780.—On the Use of Cellular Caissons. With 1 sheet of Drawings. (Vol. lxiv., p. 321.)
- , J. O. No. 1,818.—Felling Chimneys.
- Bellasis, E. S. No. 1,832.—On the Heads of Irrigation Canals supplied for the Rivers of the Punjab. With 3 Drawings.
- Bender, C. B. No. 1,770.—The Action of High Winds on Lofty and Exposed Structures, and the best Method of Determining the Force of the Wind. With 3 Diagrams.
- Bowers, F. No. 1,811.—On the Reclamation Works in Chichester Harbour.
- Bruce, W. D. No. 1820.—The Port of Calcutta and the Works constructed therein from 1870 to 1880.
- Brunton, R. H. No. 1,790. The Production of Paraffin and Paraffin Oils. With Illustrations. (Vol. lxvi., p. 180.)
- Buck, J. H. W. No. 1,782.—The Weights of Framed Girders and Roofs. (Vol. lxvii., p. 331.)
- Burnett, R. R. No. 1,834.—(a) Engineering in the Interior of China. (b) A few Notes on Mining in Wet Ground. With 2 Appendices and 13 Sheets of Drawings.
- Butter, H. J. No. 1,828.—Forces and Strains of Recoil, considered with reference to the Elastic Field Gun-Carriage. With Illustrations. (Vol. lxvii., p. 122.)
- Carrington, W. T. H. No. 1,792.—Three Systems of Wire-Rope Transport. With 4 Drawings. (Vol. lxv., p. 299.)

AUTHORS.

- Collingwood, W. No. 1,787.—On the Utilisation of Old Railway Material in India.
- Colyer, F. No. 1,771.—On the Design and Construction of Breweries, including their Plant and Machinery.
- Cundy, J. No. 1,823.—Light Scaffolding. With 1 sheet of Drawings.
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10 January, 1882.

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LEON LANGUET, Stud. Inst. C.E.		Inst. C.E.

Sir W. G. Armstrong addressed the Meeting in the following terms on taking the chair, for the first time, after his election as President:—

It has been the practice of my predecessors in the chair I have now the honour to occupy, to select topics for their address that have reference to branches of engineering which operate to increase the productiveness of human industry, and there are many who will contend that all engineering efforts ought to centre upon that object. It may be fully admitted that the general amelioration of the material condition of the world is the noblest object of our science; and if men and nations ceased to be bellicose and rapacious, such would naturally be the direction which all engineering practice would take; but we live in a world of contention, where no individual state can insure its independence, and carry on its industrial occupations in safety, without protecting itself against the possible aggression of its neighbours. Thus it is that the science of the engineer is invoked for the purposes of war as well as for those of peace; and it is probable that the engineering element will in future enter more and more largely into the operations of war, until the issue will be chiefly dependent upon the superiority of mechanical resource displayed by one or other of the contending parties. There is no country in the world less disposed to be aggressive than our own, but there is none so likely to incite the greed of an assailant, or so vulnerable in relation to its commerce. War indemnities have degenerated into mere exactions proportioned to the wealth of the vanquished; and England, being the richest of nations, offers the highest premium for successful attack. As to commerce, we have more than half of the ocean carrying trade of the whole world in our hands, and our ships, swarming over every sea and conveying merchandise of enormous value, would, in the event of war, invite the depredations of hostile cruisers. We have seen in recent years what ravages a single armed ship can inflict upon a mercantile navy incomparably smaller than our own, and, in our case, it is not only property, but indispensable food that is at stake. The ever-increasing population of Great Britain has already far outgrown its internal means of support, while the increasing cheapness of imported food so discourages native agriculture, that we may expect our future dependence upon foreign supply to increase even more rapidly than our population. This is not the occasion to discuss either moral questions affecting war, or political questions concerning free trade. We have the stern fact before us that national defence is in our case peculiarly a necessity, and the



question how it can best be effected, from an engineer's point of view, is a legitimate subject for this address.

England must always be chiefly dependent for security upon her naval power, but we cannot hope that she will ever again be so dominant at sea as before the introduction of steam navigation. So long as naval superiority depended upon seamanship and an unlimited supply of sailors, no nation or combination of nations could compete with us; but as soon as it became established that fighting-ships could be manœuvred, with more certainty and precision, by the power of steam than by the power of wind, a revolution began which has gradually made naval warfare a matter of engineering rather than of seamanship. The introduction of rifled ordnance and percussion shells was the second step in this revolution, and had the effect of condemning as useless the whole fleet of wooden ships with which all our victories had been won, and which were the pride of the nation. Then commenced that contest between guns and armour which has gone on to this day, and has not yet been decided. Nor will it, in all probability, ever be decided, seeing what an *ignis fatuus* finality is. The most recent stage of this revolution is that marked by the introduction of torpedoes, against which our ponderous ironclads are no more secure than ships of thinnest iron. These constantly-changing phases of attack and defence have placed our naval authorities under extreme difficulty in deciding upon questions of ships and armament. To stand still was impossible, while to act upon uncertain data was sure to lead to mistake. The necessary consequence has been that types and patterns of ships have been continually changing, and vessels, costing vast sums of money, have become nearly obsolete almost as soon as made. We cannot wonder that, so long as invulnerability was conceived to be attainable, great sacrifice should be made for its accomplishment; but with our present knowledge, which it would be unfair to apply to a criticism of the past, we may feel assured that invulnerability is a chimera. Not only do we see that armour is unavailing against torpedo attack and ramming, but we are justified in concluding that every attempt to increase resistance to projectiles will be quickly followed by a corresponding increase in the power of artillery. Our early ironclads, like the "Warrior," were plated all over with armour of $4\frac{1}{2}$ inches thick—a thickness which could now be pierced with field-pieces. To resist the most powerful guns now afloat, armour of at least 2 feet in thickness is required; and in order to reconcile the constantly-increasing thickness with the weight which the ship is capable of carrying, it has been

necessary to restrict the area of armour surface to ever-narrowing limits, leaving a large portion of the ship without protection. In those magnificent and tremendous vessels which the Italians are now building, the armour will be withdrawn from every part except the battery, where guns of 100 tons will be placed, and where the armour will be confined to a narrow belt of great thickness. Everything of importance that projectiles can destroy will be kept below water-level, and, so far as artillery fire is concerned, the ships will be secured against sinking by means of an underwater deck and ample division into compartments. Armour therefore seems gradually contracting to the vanishing point; but, until it actually disappear, it is probable that no better application of it can be made than has been decided upon by the acute and enterprising naval authorities of Italy for the great ships they are now constructing.

The quality of armour plates has of late been greatly improved by making the outward side hard and the inner side soft. By this means a steel facing may be used without that great liability to fracture which previously disqualified steel as a material for armour plates. This improvement will probably give fresh encouragement to those who advocate the continued use of armour; but, even if the victory of armour over guns should ever be established, it would still be a question whether it would be worth while to incur the enormous expense incident to the use of armour, for the one advantage of resisting projectiles, seeing that however invulnerable by shot a ship may be rendered, it must remain equally assailable by rams and torpedoes, and equally liable to be lost by casualties other than those of war.

The dread of the terrible effects of the fragments of shells bursting amidst a crowded crew, and the apprehension that the smoke from the explosion, when it occurred between decks, would paralyse the service of the guns, have conduced more than anything else to the adoption of armour. Methods of avoiding or lessening these dangers, otherwise than by the use of armour, have been little considered; yet the alarming aspect of the case is greatly altered when we reflect that, by the application of mechanical power to do what has hitherto been done by a multitude of hands, the exposure of a crowded crew can be avoided, and also that the guns may all be mounted on an open deck, where the smoke from shells would speedily clear away. It is a recognised fact that the function of armour may in a very considerable degree be fulfilled by the coal, if judiciously applied for that purpose. The resistance of coal to the penetration of shot is very remarkable. By experiments made

last year, at Shoeburyness, it was found that, with a 6-inch new type gun, capable of piercing an iron plate of $10\frac{1}{2}$ inches thick, a resistance equal to that of the armour was offered by 18 feet of coal; and that with an 8-inch gun of the same type, capable of piercing $13\frac{1}{2}$ inches of similar armour, an equivalent resistance was obtained with $26\frac{1}{2}$ feet of coal. The deadening effect of coal upon the explosion of shells is still more remarkable. The Committee, under whose direction the experiments were made, reported that the bursting of common shells had no igniting effect upon the coal, and little or no disruptive effect upon the structure containing it. As to the destructive effect of shells upon a crew, in a ship where no protection of any kind is used, I venture to think that the reality would fall much short of the anticipation. Percussion shells do not burst instantaneously on striking, but travel about 6 or 8 feet after free penetration before they explode. The fragments then begin to disperse, but, retaining the forward motion of the shell, while deflected by the action of the bursting charge, they form a cone of dispersion, the angle of which is determined by the relation between the forward and lateral velocities of the pieces. It is only within this cone that the disrupted shell can do any harm; and as the shell will generally enter on the fighting side of the ship where the men would be placed, the fragments would there cover a very small area, and would only attain their maximum dispersion at the opposite or unoccupied side. This would not be true of a shell entering in a raking direction, but it is a principal object of manœuvring to avoid exposure to a raking fire. An absolutely unprotected ship would probably suffer more from machine-guns than from shell fire; but there would be comparatively little objection to making the skin of the ship, at the gun-deck, sufficiently thick to resist missiles which can be discharged in showers from those weapons.

As to the comparative liability of an ironclad and an unarmoured ship to be sunk by projectiles, there is much less difference between them than is generally supposed; because the unarmoured ship, though freely penetrable, may be so constructed that the entrance of water by perforation would not extensively flood the ship, unless it took place at a great number of critical places. Indeed, by introducing an under-water deck, with divisional spaces, and by the partial application of cork, as in the "Inflexible," for displacing influent water, and thereby preserving stability, and also by a proper distribution of coal for the same purpose, an unarmoured ship may be rendered almost incapable of being sunk; and it is rather surprising that so little attention has been directed to the attainment of that object.

It is not too much to say that for the cost of one ironclad we could have three unarmoured ships of far higher speed, and carrying collectively three armaments, each equal to that of the armoured vessel. We may ask, Which would be the better investment? If we imagine the three to be matched in combat against the one, we perceive that, in addition to their numerical superiority, they would possess many advantages. Being smaller, they would be more difficult to hit. Being swifter, they could choose their positions, and be free to attack or retreat at pleasure. Being more nimble in turning, they would be better adapted both for ramming and for evading the ram of their adversary. Finally, the conditions of superior speed and agility would favour their use of torpedoes and submarine projectiles; although it is a question whether, for the sake of a much-needed simplification, it would not be better to confine that species of attack to separate vessels specially constructed for that one particular purpose. Even if we concede to the ironclad the utmost advantage she could possess—viz., that of being impenetrable by the guns of her opponents—she could not prevail in a contest of three against one, unless by the use of her securely-protected artillery she could keep her assailants at bay, and gradually destroy them by her fire if they persisted in their attack. Such might be the issue if the allied vessels had nothing but guns to oppose to guns; but they would naturally, under such circumstances, place their men below, out of the reach of projectiles, and then attack with their rams or torpedoes. With the crews in safety, it is scarcely possible that unarmoured vessels, with underwater decks and all their machinery beneath, should suffer any disabling injury by being pierced in a few places by either shot or shell. But let us next take the much more probable alternative of the armoured vessel being penetrable by the guns which would be used against her. In that case her enemies might elect to make the contest one of artillery. On their part, armour-piercing projectiles would be used which, on penetrating the thick sides of the ironclad, would carry inboard a mass of broken material far larger in quantity than the fragments of the shells with which they would be assailed, and quite as destructive in effect. The ironclad would have to sustain the converging fire of three ships, each carrying the same armament as her own, and her swift and nimble adversaries would steam round and round her, directing their fire on the most vulnerable points, and ever ready to seize a favourable moment to dash in and finish the contest by ramming. In either case, therefore, the ironclad would be over-matched by a combination of unarmoured vessels representing the same pecuniary value. Without entering into technical questions concerning fleet-fighting, it seems

reasonable to believe that the result would be the same if the number engaged on each side were proportionately multiplied. Superiority of speed and of number would still give the choice of position, and secure the advantage of converging fire, besides which the greater power of division and of concentration must always belong to the more numerous fleet. But if ironclads be not needed for the purpose of opposing ironclads, it is difficult to see for what purpose they are wanted at all. For every other kind of service, a numerous fleet of smaller and swifter vessels, unencumbered with armour, would clearly be preferable. To protect our commerce, to guard our extensive seaboard against invading flotillas, to lend naval assistance to our colonies in case of need, and generally to maintain our supremacy at sea, we require a far more numerous navy than we possess, or can afford to possess, unless we vastly reduce our expenditure on individual ships, and to do this we must dispense with armour. It might, perhaps, be rash entirely to abandon armour so long as other nations continue to use it, because nothing but the experience of an actual war will remove all question as to its possible utility; but considering the indisputable value of a numerous fleet of swift and powerfully-armed ships, built with a view of obtaining the maximum amount of unarmoured defence, and considering that such vessels, unlike armour-clads, can never grow much out of date, it does seem to be expedient that the chief expenditure of this country should be upon ships of that description. Lightness should be the special aim in the construction of such vessels. Steel plates should be used for the hulls, and guns and engines should be of the least possible weight consistent with the necessary power. Every ton of weight which is saved will enable higher speed to be attained, and there is probably no quality in a fighting ship which will so much develop in importance as that of swiftness. Messrs. Thornycroft have led the way in showing what extraordinary speed can be realised in diminutive vessels by reducing to the utmost the weight of every part of the structure and its contents; and although we cannot expect to attain proportionate speed by the same method in ocean-going ships of war, yet there can be no question that we may have far swifter ships than at present if we make lightness our principal object, instead of following the previous practice of loading our ships with cumbrous armour, in the vain hope of rendering them invulnerable. Light unarmoured ships, designed by Mr. George Rendel, have lately been built in this country for foreign powers, which, with a displacement of only 1,300 tons, have attained a speed of 16 knots an hour. They carry coal for

steaming 4,000 miles, and have already actually steamed 3,500 miles without replenishing. They are each armed with two 10-inch new type guns which have nearly an all-round fire, and are capable of piercing 18 inches of iron armour; and with four 40-pounders on the broadsides. It is a very serious question what we are prepared to do in the event of a number of such vessels as these being let loose upon our commerce. At present there is not a single ship in the British navy carrying an armament competent to engage them, that could overtake them in pursuit, or evade their attack when prudence dictated a retreat. Confidence is often expressed in our mercantile marine being capable of furnishing, on an emergency, a supply of vessels fit to be converted into cruisers; but where are we to find, amongst our trading or passenger steamers, vessels possessing a speed of 16 knots, with engines and boilers below water-level, and having an under-water deck to save them from sinking when penetrated by projectiles at or below the water-line? From my own experience I know how difficult it is to adapt mercantile vessels to the purposes of war, and how unsatisfactory they are when the best has been made of them. It is alarming to think how unprepared we are to repress the ravages which even a small number of swift marauding vessels, properly constructed and armed for their purpose, could inflict upon the enormous property we have at all times afloat, and how little we can hope to clear the sea of such destructive enemies by cruisers improvised out of ready-made steamers destitute of all the conditions necessary to render them efficient for such a service. We must ever bear in mind that it is not merely the loss of property and interruption of trade that we have to fear, but also the interception of our food supplies; and that the more our population increases and our agriculture declines, the more terribly effective for reducing us to submission would be the stoppage of those supplies.

Another branch of national defence, which in a great measure falls within the province of the engineer, is that which applies to the protection of harbours. Very little has yet been done for securing our commercial harbours from attack, and it is to be feared that immense damage might be done by the incursions of hostile cruisers that succeeded in evading the vigilance of our insufficiently numerous navy. Our naval arsenals have not shared in this neglect, but the efficiency of the defences which have been provided for their protection may well be questioned. Vast sums have been spent in the erection of ironclad forts which have already outlived that stage of artillery progress for which they were adapted, and to this day it remains a problem how to make the

limited space they afford available for artillery of the necessary power. Even if they admitted of being adequately armed, it is not easy to see how large guns, crowded together in double tiers, as is the case in many of these forts, could be fired at a passing object without creating such an amount of smoke and confusion as would be incompatible with the efficient service of the guns. To render large guns effective in shore batteries, they should be mounted well clear of each other, so that the smoke from one should not interfere with the sight from another, and I am not alone in my opinion that wherever the old-fashioned system of earthwork is practicable, it will be found the best and cheapest kind of protection. Muzzle-loading guns can be mounted in such a manner that they can be very easily turned and depressed, so as to be loaded under the shelter of an earthen parapet, by hand-worked machinery of the very simplest description. Damage done to an earthwork by an enemy's fire admits of easy and immediate repair, while damage to an ironclad fort can only be rectified at great cost and after much delay. Guns mounted in earthworks can be rendered difficult to see, and when well separated they can bring a converging fire upon a ship, which can only be answered by a dispersive fire on her part. A great ironclad fort presents a large and conspicuous target for convergent fire, and the veil of smoke which would envelop it would afford little or no protection against the fire of attacking ships, while its own gunners would be unable to see the objects to be fired at. The guns also in these iron forts, instead of having a free lateral range as they would have over a parapet, project through contracted port-holes which restrict to narrow limits the lateral angle of fire, and equally contract the view of passing objects. Many of the ironclad batteries that have been erected are built as islands in the sea, where earthworks are impossible; and it may be contended that shore batteries would in these cases be too distant to command the channel; but, it may be asked, Are not floating defences preferable, under such circumstances, to insular batteries, both in point of cost and efficiency? Gun-boats, constructed as mere floating gun-carriages, can be made to carry the heaviest artillery. They would present only very small targets to the enemy's fire, and, at the varying distances at which they would be used, they would be extremely difficult to hit. They could be spread out so as to clear each other's smoke, and bring a converging fire to bear upon a single ship. They could retreat, when necessary, into shallow water, and in many cases maintain a fire over breakwaters which would afford them protection. Instead of being rooted to one spot like

a battery, they could pursue, or retreat, or unite in taking up new positions, and they could perform many services to aid or relieve a fleet. Combined with steam-launches armed with torpedoes, they would afford a flexible and powerful means of defence, and will probably still have to be adopted even where iron-cased batteries have already been erected. At all events, for the protection of commercial harbours, gun-boats, thus associated with torpedo craft, would be far more effective than fixed batteries of any kind, and the first step towards making our commercial harbours independent of external naval protection appears to be to furnish each of them with a sufficient number of such vessels, which might be placed in the hands of trained volunteers resident on the spot.

But no system of harbour defence can be deemed complete that does not embrace the application of submarine mines, which, by electrical connection or severance, effected on shore, can be rendered explosive or harmless to passing vessels at the will of the operator. There is probably no mode of defence that would have such a deterrent effect upon an enemy as that of submarine mines, the management of which might also be intrusted to properly instructed volunteers. It would be a grand development of the volunteer movement, of which this country is so justly proud, if it were thus to be extended to harbour defence; and I am informed that, so far as the use of submerged torpedoes is concerned, a project of intrusting their employment to a corps of volunteer engineers is already under consideration. The superior education and intelligence of the class from which our volunteers are mostly supplied would especially fit them for the discharge of duties involving skill and discretion, such as would be required in the handling of electrical apparatus, and we may be sure that, wherever dash was needed in the use of torpedo-boats, there would be no lack of that quality amongst volunteers in the hour of trial.

The subject of artillery forms a most important element in all questions of national defence, and as it is one which has in a special degree fallen within the scope of my experience, I may be expected to make it a prominent topic of this address.

Before the introduction of rifled ordnance, a gun was simply a tube of cast iron or bronze, closed at one end. The bore was smooth, the projectile was spherical, and the charge was small. Guns thus made fulfilled the purposes of the day, but, when rifling was adopted, an elongated shot had to be used, far heavier than the round shot of corresponding diameter. Rotative motion had also to be given to the projectile, in addition to the forward motion,

and the increased strain due to these altered conditions was more than the old guns, when rifled, would bear. Their insufficient strength was attributable partly to the inherent weakness of the material, partly to the weakening effect of the rifling, and partly to a constructive defect which had been previously pointed out by Professor Barlow in relation to hydraulic presses. In his treatise on the strength of materials he shows that the strength of a cast-iron cylinder is far from being proportionate to its thickness, because the internal layer of the metal may, from its shorter circumferential length, be stretched to the breaking point before the external layer has nearly reached the limit of its resistance. He further shows that, in order to obtain the greatest resistance to a bursting force in a cylinder, the external layer of the material must be in a state of initial tension, which should diminish in each succeeding inward layer until a neutral point is reached, beyond which a state of compression must prevail, gradually increasing to a maximum at the interior surface. To comply with these conditions a gun requires to be built up in successive layers, each layer being contracted upon the one beneath; and the more numerous the layers, the nearer will it approach to theoretical perfection. Much mathematical refinement has been expended in the attempt to define the precise degree of contraction which should be given to each successive layer; but this critical nicety does not appear to be important provided the contraction be on the excess side of what is mathematically correct. There is no harm in giving a hoop a little permanent stretch by shrinkage, and if the interior of the gun be more compressed than theory requires, the tendency of the explosive force is to effect an adjustment. The advantage of external tension is now universally recognised, and no large guns are made without an envelopment of initially-strained material. It is to be observed, however, that mere hoops shrunk upon an internal tube, give no end strength to the gun, and the tube must in that case be made sufficiently thick to carry the whole longitudinal strain. But since a thick tube approaches the objectionable condition of a solid gun, it is better to reduce the thickness of the tube, and supplement its deficient end strength by longitudinal strength in the surrounding material. Much less strength, however, is required longitudinally than transversely, and therefore the material may, in a corresponding degree, be weaker in the direction of the length than in that of the diameter. This condition is fulfilled by the coiled iron cylinders, which were introduced by myself, and which depend for longitudinal strength upon lateral welds, but resist the more potent bursting strain by the continuous

fibre of the rolled iron employed in their fabrication. The barrels of fowling-pieces had long been made upon this principle, viz., by welding a spiral coil of soft iron into a continuous tube, and that mode of construction was justly esteemed for the safety it afforded. But for the inner tube of a built-up gun a harder and more homogeneous material is required than welded iron, and I have always used steel for that purpose when I could obtain it of suitable quality, which, in the early days of my experience, was a difficult thing to accomplish.

The term steel, as now used, is a very indefinite one. Formerly it implied iron so combined with carbon as to render it susceptible of a high degree of hardening by immersion in a cold liquid; but it is now more generally applied to iron which is produced by a process of fusion, instead of by one of adhesion, and in that sense it is independent of any particular degree of carbonisation. Using the term in this sense, steel has the advantage over iron in being free from defects of welding. It generally contains more carbon than wrought iron, which renders it stronger. It is also tougher under some tests, but more prone to fracture under others. This tendency to fracture has been strongly exhibited where the material was exposed to the concussive action of gunpowder; and it is notorious that steel armour plates, even of the softest and toughest description, are, or at all events have hitherto been, much more easily fractured by the impact of a shot than similar plates of wrought iron. But the manufacture of steel continues to improve, while that of iron is stationary, and the time is probably near when the manufacture of iron, as now practised, will entirely merge into that of steel, as produced by the process of fusion.

The question then arises, What, under the present condition and prospects of steel manufacture, should be our practice as to the use of that material for artillery purposes?

As regards the internal tube, there is not, and never has been, any doubt in my mind that steel is the proper material. Iron is too soft for the purpose, and the welded junctions are easily eroded by the action of the exploded powder. I do not mean to disparage the use of a wrought-iron coil tube as a lining for old cast-iron guns, by which mode of treatment a serviceable class of rifled gun can be produced for light work; but the success attained with guns of that description does not justify the application of a similar mode of construction to ordnance in which the highest possible power is sought to be attained. As to the material for the envelopment of the tube, the choice lies between steel and wrought iron. The only large experience in this country has been with guns

jacketed with welded cylinders made of coiled wrought-iron bars, and no system of construction has been elsewhere so amply tried in relation to heavy artillery. As to the results, a comparison may be challenged with any foreign system in regard to the paucity of accidents in proportion to the extent of the firing.

But the problem is ever before us how to lessen the weight and increase the power of heavy ordnance, and we cannot rest satisfied with results, however good, if they be not the best that appear to be attainable. In saying this I am led to speak of a system of construction which has not yet passed through the experimental stage, but which, from the results it has already given, promises to attain a wide application. I refer to that system in which the coils surrounding the central tube consist of steel wire, or ribbons of steel, wound spirally upon the tube. To those who object to welded coil tubes on the ground of supposed deficiency of longitudinal strength, this mode of construction must appear especially faulty, inasmuch as lateral adhesion, instead of being, as contended, merely deficient, is altogether absent; while to those who advocate the present coil system, this variety of it must commend itself as affording the greatest possible amount of circumferential strength that can be realised from the material employed. Steel in the form of wire, or drawn ribbon, possesses far greater tenacity, and also greater toughness, than in any other condition, and in applying it to guns we have perfect command of the tension with which each layer is laid on. The idea of using wire for this purpose is far from new. It formed the subject of a patent obtained by Captain Blakely in February 1855, and also of a patent taken by Mr. Longridge a few months later, soon after which time the late Mr. Brunel conceived the same idea, and, in ignorance of the existence of any patents on the subject, commissioned me to make for him a cannon upon this principle; but, as soon as he discovered that the ground was occupied by patents, he gave up the project, and for the same reason I abandoned it myself. Mr. Longridge has persistently advocated the use of wire for this purpose, and has more than once brought the subject before this Institution. He has also suggested a form of gun designed with a view of obviating the objection of want of longitudinal strength, but I am not aware that his method of construction has been reduced to practice. Of the theoretical advantage of this system there can be no doubt, but the difficulties only begin when we endeavour to put the theory into practice, and no solution of the problem of how to do it can be accepted without the production and trial of an actual gun. My own attention was redirected to the subject nearly five years ago,

when the patents had long expired; and, after making various preliminary trials with small wired cylinders, a 6-inch breech-loading gun of this construction was commenced in 1879 and finished in the beginning of the following year, since which it has undergone many severe trials. The charges used with it were large beyond precedent, and the energies developed proportionately high. Being satisfied with the results obtained with this gun, a second one, of larger dimensions, was commenced and is now finished. Its calibre is 26 centimetres, or about $10\frac{1}{4}$ inches. Its length is 29 calibres, and its weight is 21 tons. In the previous gun I depended for end strength upon the thickness of barrel only; but in the new one, layers of longitudinal ribbons are interposed between the coils, in the proportion of one longitudinal layer to four circular layers. The longitudinals are secured to the trunnion ring at one end and to a breech ring at the other, and are in themselves calculated as sufficient to resist the end strain on the breech, independently of the strength afforded by the tube. The whole is incased in hoops shrunk upon the exterior of the coil, for the treble purpose of protection from injury, of preventing slipping in the event of the failure of an external strand, and of adding to the strength of the gun. This gun has already been tried, and given results which, in relation to its weight, are unexampled except by its 6-inch predecessor. Various attempts have also been made abroad to reduce this system to practice, and it is understood that the French are at present engaged in making experimental guns upon the same general principle. With regard to the ribbon form of section, I prefer it to a square section of equal area, as being more favourable for bending over a cylinder, but any rectangular form is better than round wire, on account of the flat bedding surfaces it affords.

The question whether breech-loading or muzzle-loading guns are most advantageous is one which has been discussed in a very uncompromising spirit, as if one or other of the two systems ought to be universally adopted to the entire exclusion of the other. Impartial consideration, however, will show that there is room for both systems, and that each is best in its proper place. It has been distinctly proved that, so far as accuracy and velocity are concerned, there is nothing to choose between them. Neither is there any material difference in regard to rapidity of fire; nor would a superiority in this respect on either side be of much value, seeing that it is of far more importance to cultivate careful and deliberate fire than to facilitate a lavish expenditure of the very limited supply of costly ammunition that can be assigned to each

gun in active service. With regard to convenience of loading and security of the gunners, the advantage is mostly, though not invariably, on the side of the breech-loader. Guns mounted on the broadsides of ships or in casemated batteries cannot be loaded at the muzzle by any known method without very seriously exposing the men to the fire of machine guns and small-arms. In fact, the great length of modern guns renders it impossible to get access to the muzzle for the purpose of loading, without allowing more space for recoil than is practicable in a ship, or in the usually confined space of a casemate; so that in these instances breech-loading must be regarded as a necessity. But in earthwork batteries a muzzle-loading gun can, by proper arrangement, be loaded under the shelter of the parapet more securely and quite as conveniently as a breech-loader. In revolving turrets also, a gun may be loaded at the muzzle by external means, involving no exposure of the men, and in gunboats carrying a heavy gun on the line of the keel, loading at the muzzle is also easily effected. The superior simplicity of a muzzle-loading gun entitles it to a preference wherever it can be used with equal advantage. All breech-loading mechanism is of a nature to require very accurate fittings, such as demand care both in use and for preservation. Breech-loaders, therefore, are very unfit weapons for imperfectly instructed gunners, and they are quite out of place in open batteries, where they would be exposed to the injurious influences of the weather, and of drifting sand. It would be folly, therefore, in such cases to use them in preference to muzzle-loaders, which need little care for their preservation, and take no harm from exposure.

The various methods of breech-loading may be classed under two heads: 1st, breech-loaders with a closing apparatus worked from the side; and, 2nd, breech-loaders closed by a screw inserted at the rear. In the former class a large opening is required through the gun, the continuity of which is thereby interrupted to the detriment of longitudinal strength, while in the latter class the stronger form of a continuous cylinder is maintained to the extreme rear, and the necessary end strength is obtained with less weight of material behind the base of the bore. The numerous turns which would be necessary for inserting and withdrawing an ordinary screw are avoided in the French practice, by cutting away such portions, both of the inner and outer thread, as will permit of the remaining portions being engaged and disengaged by revolving the screw through a part only of a single turn. This method necessitates the use of a larger screw than would otherwise be needed, because half of the entire thread is removed; but there is

no difficulty in realising sufficient holding power with a screw of moderate dimensions when thus cut away. The system which of late years has been adopted at Elswick is that of the French cut-away screw, combined with a new cup arrangement for stopping the gas; and our Government, acting upon trials made with guns supplied by my firm, are at present doing the same.

I now come to the subject of rifling, which has given rise almost as much controversy as the question whether guns should be loaded at the breech or at the muzzle. The sole object of rifling is to communicate to the projectile a sufficiently rapid rotation to give it gyroscopic steadiness in flight, and it is objectionable to use a quicker spiral than is necessary for this purpose. After long experience, it seems to be now generally admitted that with projectiles proportioned according to general practice, which appears to be nearly the same in England and abroad, a twist not exceeding one turn in thirty-five calibres for small guns, and from that to one in fifty for large guns, is sufficient for the purpose. But if we increase the length of the projectile, a quicker rotation becomes necessary to steady it, and this involves a more rapid twist in the grooves. Rifling is said to be uniform when its pitch is the same throughout the bore. In that case the tangential force producing rotation is a constant proportion of the pressure on the base of the shot. Therefore, the pressure on the base being greatest at first, the tangential strain is also greatest at first; and as the propelling force diminishes, so does the tangential force decline. To remedy this inequality of tangential force, and make the strain upon the grooves nearly equal throughout, it is common practice to lessen the pitch at the commencement, where the pressure is greatest, and let it gradually increase towards the muzzle as the pressure diminishes. This is called an accelerated twist, and its one disadvantage is that it is attended with rather more loss of energy in friction than is incident to the uniform spiral; but the difference is too small to be important.


The various systems of rifling may be referred to under three heads: 1st, that in which rotation is given by studs projecting in large and deep grooves in the gun; 2nd, that in which the form of the bore is adapted to give rotation by the mechanical fit of the shot; and, 3rd, that in which the rotation is produced by attaching to the projectile a soft material, which, by expansion in the case of muzzle-loaders, and by crushing in the case of breech-loaders, moulds itself to the form of the rifling, and stops the windage. The first, or studded system, is that which has for many years been applied to the guns of the British service; but guns of the

rifled require to be used with metallic gas checks to prevent windage; and when these are made of a form to fit the grooves, and are adapted to grip the base of the projectile, the studs are uncalled for. The second, or mechanical-fit system, is only applicable to a uniform twist. I abstain from reviving controversy on this mode of rifling, which, though powerfully advocated, has not met with extensive adoption. The third, or soft-metal system, is that which meets with most favour, both in England and on the Continent. It involves no departure from the cylindrical form of bore, which is the strongest form. It admits of the grooves being numerous and shallow, instead of few and deep, which is also favourable to strength. It suppresses windage better than any other system, and it adapts itself to an accelerating twist. All the new-type guns made at Elswick and at Woolwich are rifled to suit this system, the material used on the projectile being copper, applied as a hoop for breech-loaders and as a cup for muzzle-loaders. The accelerating spiral thus used in conjunction with soft metal on the shot has this additional advantage: that in the early stage of the shot's motion, when it is especially desirable to keep the grooves closed against windage, it lessens the edge-wear on the soft metal in the grooves, and thereby tends to keep them filled with the material—an effect which is aided by the slight distortion of the soft metal produced by the increase of pitch.

Another question, which has also given rise to much controversy, is whether we should lean towards large bores or small bores in artillery construction; and upon this subject I shall say only a few words. In judging of the best calibre for a gun, it is necessary in the first place to decide the amount of powder in the charge, and how much expansive action has to be allowed to the powder gases before they are discharged. Taking 120 cubic inches as a fair allowance for each pound of powder, we arrive at the total capacity of the bore by multiplying that number of cubic inches by the pounds' weight in the charge. It will then remain to be decided how far the required capacity shall be provided by width, and how far by length, of bore. If we increase the width, we gain capacity in the ratio of the square of the diameter; but if we increase the length, we only gain in the direct proportion of the length. We have also to be largely guided by considerations affecting the projectile. Assuming its weight to be fixed, its length will determine its diameter; so that a long shot implies a small bore. A lengthened projectile has both advantages and disadvantages. It meets with less atmospheric resistance, and therefore loses less energy in its flight. It has greater penetration,

because it has a smaller hole to make; but the superiority in respect is only in proportion to the circumference, and not the length of the hole. On the other hand, the lengthening of a shot increases its tendency to crush or break on striking. Used as a shell, a long projectile contains less powder than a short one of equal weight and larger diameter, and is more liable to break by impact before explosion. Finally, a long projectile requires more rapid rotation to steady it, and this involves greater tangential strain on the grooves and greater expenditure of power in producing rotation. The question of calibre is therefore a very complex one, and it can only be settled by a compromise of conflicting considerations. The tendency of recent practice has been rather towards a reduction of calibre; and this, combined with a large increase of charge, has necessitated the great length which characterises the most modern ordnance, and constitutes the principal argument in favour of breech-loading.

The better knowledge which we now possess concerning the forces of fired gunpowder has greatly facilitated the recent progress of artillery. Before the elaborate papers on this subject, which were contributed by Captain Noble and Professor Abel to the "Transactions of the Royal Society" in 1874 and 1879, the distribution of strength in a gun had to be fixed in ignorance of the true pressures to be resisted in the various parts of the bore; the modes of moderating the initial pressure of the gas were imperfectly understood. Much has already been done, and much remains to be done, to adapt gunpowder to all the conditions of modern ordnance. In the old round-shot guns, the charge was small and the bore relatively large, the cartridge was short, the igniting flame had a very small distance to travel in order to reach the extremities. Moreover, the spherical shot acquired velocity much more rapidly than the elongated shot of the modern gun, and, owing to the wider bore, in relation to the length of the cartridge, given distances traversed by the shot effected large reductions of pressure by expansion. Hence, therefore, although the powder was small in grain and completely ignited, the strain on the gun was more moderate and transitory than in the modern bore. In it the length of the cartridge was greatly increased, the igniting flame had much further to travel in order to reach the remoter parts of the charge. The granular interstices were too small to permit the flame to penetrate with sufficient freedom, and portions of the charge got jammed into solid masses, which were burnt so slowly as to result in a large proportion of the powder either not being burnt at all, or burnt at so late a stage of




process as to be of little avail for propelling the shot. It therefore became necessary to abandon powder of the granular form, and make it in pebble-like pieces, which would burn more slowly and afford more interstitial space for the penetration of flame. As guns grew larger and charges increased in length, it was found necessary to enlarge the separate pieces, until at length each one of them became a lump of powder weighing several ounces. The lengthening of the charge has gone on to such an extent that in some cases the cartridge has attained upwards of six feet in length, and the consequence is that the gas, rushing from the point of ignition to the ends of the powder chamber, and there being suddenly arrested, produces a zone of high pressure, within which the powder burns abnormally fast. Then a back rush takes place, and a violent wave action is set up, resulting in local strains of great severity on the gun, without materially affecting the velocity of the shot. This dynamic action of the exploded charge is mitigated by slow-burning powder, but the chief preventive is central ignition, and ample flame space both through and around the cartridge. The prismatic form of powder, long used abroad before it was manufactured in England, is probably the best, so far as shape is concerned. The prisms, being perforated hexagons, pack into small compass, and afford numerous passages for flame, the diffusion of which can be further facilitated by omitting the central prism. But even this kind of powder is subject to wave action in a long closely-filled chamber, unless the powder be of very slow-burning quality, in which case it is subject to incomplete or too tardy combustion.

Another very formidable evil attending the use of large charges of powder is the erosive effect of the products of combustion upon the bore of the gun. When a charge of powder is fired, it is converted into a mass of intensely-heated gaseous and liquid matter, of which the liquid portion is more than equal to the gaseous. This highly-heated liquid, being thrown into violent motion, exercises on the bore a scouring action which seriously lessens the endurance of the gun, and sometimes endangers its stability by forming deep gutters which are liable to develop into fissures under the stress of the firing. The action is partly chemical and partly mechanical, and so far as the chemical action is concerned, is probably chiefly due to the sulphur in the powder. It therefore becomes an important and interesting question whether that ingredient cannot be dispensed with. Sulphur is undoubtedly useful to aid the ignition where small charges are used, and it probably increases the heat, and thereby augments the force, but in large

charges it is desirable to repress both quickness of ignition and heat of combustion. The sulphur adds little or nothing to the gaseous products of the combustion, and, if its place were supplied by an addition to the carbon, an increased volume of gas would be evolved. If the composition of gunpowder cannot be so modified as greatly to reduce the present erosion, renewed efforts should be made to find some other explosive substance more fitted for heavy artillery. Gun-cotton and other compounds of that nature have the advantage of being almost entirely free from residuum, but, owing to the instable equilibrium of their component parts, they are liable to detonative explosion of dangerous violence. The excessive heat of their ignition might also prove an objection as tending to fuse the surface of the bore. The calculated heat of fired gunpowder is $2,100^{\circ}$ C., while that of gun-cotton is about $4,500^{\circ}$ C. Captain Nolte found that platinum foil enclosed in a cartridge of gunpowder fired in a closed vessel, was barely fused, but in a cartridge of gun-cotton it was not only fused but volatilised. If means could be discovered of moderating this violence and high temperature, we might possibly find, in some compound of this kind, an explosive agent possessing all the efficacy of gunpowder, without its destructive action upon the gun. Until this is done, or until gunpowder is rendered more harmless, the use of full battery charges should be limited to those occasions on which the maximum power of the gun is actually required, either for the purposes of war or for those of experiment. On all other occasions the light or "service charge" will suffice, and will produce less wear upon the gun.

Had the limits of this address permitted of a complete dissertation upon modern ordnance, I should have had much to say on the subject of mounting and working heavy guns, both in ships and shore defences. As to the latter, I will merely remark that the difficulties which surround the problem of how best to mount these guns are much greater than is commonly supposed, and that the want of a decision on this subject some of our most costly forces have long since finished, remain very imperfectly armed. As to ships, the question of mounting modern guns is equally critical. It is certain that machinery can no longer be dispensed with for working the guns, and that engine power must be used if we are to economise labour and avoid exposure of men. In the days of cast-iron smooth bores the heaviest naval gun weighed 95 cwt., and was deemed impracticable to exceed that limit in a ship. At the present time the heaviest naval gun in the British service weighs 80 tons, and guns of 100 tons are carried in Italian ships. Inste



of projectiles weighing as a maximum 94 lbs., and charges of 16 lbs., we have now to handle projectiles of 1,500 lbs., and charges of 450 lbs.; and if we are to keep pace with foreign navies, we must greatly exceed those limits of weight. Even if it were possible to deal with guns and ammunition of such weights by manual labour, the multitude of men required for the purpose would be greater than could find standing-room at the guns. Up to a certain point hand-power may be so aided by machinery as to enable larger guns to be worked by men than was formerly deemed to be possible; but the mechanism required to render hand-labour available is quite as liable to be disabled by an enemy's fire as that which would be applied in connection with engine power. There is, therefore, no reason in this respect for employing a numerous gun crew in preference to inanimate power. Automatic methods of running out the gun, by which the gun is lifted in recoiling by slides or radius bars, and recovers its position by gravitation, may in many cases be advantageously used to save labour, but in a ship the varying inclination of the deck interferes with uniformity of action. The upward motion of the gun also involves the objection of a higher port, and it adds greatly to the downward shock, which becomes very severe on the deck where the guns are large and are fired at considerable elevation with such heavy charges as are now usual. Steam power, acting through the medium of hydraulic pressure, is already largely applied in recent ships for effecting all the operations of working the guns, and where such power is used there is nothing to gain by automatic action for returning the gun into firing position. In considering these various mechanical arrangements now applicable to naval warfare, we perceive the growth of the engineering element in our ships of war, and the importance of mechanical, as well as nautical, acquirements on the part of the officers, as also, in a less degree, on that of the men. Breech-loading guns, carriages fitted with all modern appliances, shot and powder lifts, mechanical rammers, and torpedo apparatus, all combined with steam or hydraulic machinery, or with both, constitute mechanisms requiring to be supervised by officers qualified as engineers, and to be handled by men trained in the use of machinery.

I must now draw to a conclusion; but, in the hope that your patience is not yet wholly exhausted, I shall, before closing, advert to a subject of grave national importance. Our navy is at present armed with guns which could not be expected to contend successfully with the best modern guns that could be used against them. Happily, most of the older ships of foreign powers are in the same

predicament; but all their new vessels, and some of their older ones, are being armed with artillery which, weight for weight, is far superior in power to that of our navy. Our service guns have simply been overtaken in that rapid progress of artillery which has been going on for the last eight or ten years; and it may be doubted whether any partial remodelling during that period would have averted the present need of re-armament; while it would certainly have involved great sacrifice and confusion of ammunition and stores. But a new departure cannot longer be delayed. An irresistible demand has arisen for breech-loading guns, and it is imperative to combine, with the introduction of that system, such other modifications of construction as will realise the increase of power which we now know to be attainable.

It may, however, be asked, What better prospect of finality have we now, than we had ten years ago? As to absolute finality, it will probably never be reached, but the country may take some comfort in the reflection that every stage of progress narrows the field for further development. There is already no substantial room for improvement in the accuracy of guns; and as to power we are nearly approaching the limit at which severity of recoil and extravagant length of gun will prohibit further advance. We may go on building larger guns almost without limit, though doubt the policy of so doing, but mere increase of size does not revolutionise system. There seems, therefore, to be more hope of permanency now than at any former period; but, whether this be so or not, we cannot, without danger, remain passive.

What, then, should our Government do in regard to the great work of re-arming the fleet? I take it for granted that all new ships will be armed with the best guns that can now be made, and that the more important of the older vessels will speedily receive the same advantage; but beyond this, so long as experience of novelties is deficient, it is a case for cautious procedure. In the meantime, no expense should be spared in judicious experiments, seeing that the expense of experiments is trifling in comparison with that of mistakes. Above all, the Government should pursue such a course as will bring into full play the abundant engineering resources of this highly mechanical country, for increasing the efficacy of our National Defences.

Being duly moved and seconded, it was resolved unanimously—That the cordial thanks of the Institution be given to the President for his Address, and that he be requested to permit it to be printed and circulated with the Minutes of Proceedings in the usual manner.

24 January, 1882.

JAMES BRUNLEES, F.R.S.E., Vice-President,
in the Chair.

(*Paper No. 1837.*)

"The Analysis of Potable Water, with special reference to
the determination of Previous Sewage Contamination."

By CHARLES WATSON FOLKARD, Associate Royal School of Mines.

As far as the examination of mineral substances is concerned, analytical chemistry is in a very advanced state. Indeed, it may be a matter of opinion as to whether any improvement is required for practical purposes. But as regards organic chemistry, especially that branch which deals with the secretions and tissues of plants and animals, the reverse is the case, and analysts are at present groping in the dark. Nor is this to be wondered at, when the enormous number, great complexity of composition, and unstable nature of these bodies are taken into account, and also the short time that has elapsed since they were first studied. It is a comparatively simple matter to estimate the percentages of the constituents of a body, in other words to make an ultimate analysis of it; and where one element forms but a few combinations with another, the relative amounts of the constituents determine which of the compounds is under investigation. But inasmuch as hundreds of organic compounds are made up of the same three or four elements, and in many even the proportions of these elements are nearly the same, it is obvious that ultimate analysis will not afford sufficient information to allow of the presence or absence of a certain substance being predicated. If the analyst receive the substance in a pure state, or if it be capable of purification by crystallisation, distillation, &c., its physical properties of specific gravity, form, colour, &c., are of great assistance in ascertaining its identity. But if a solution in water is the form in which it is received, and especially if the

solution be very dilute, the difficulties are greatly increased. When, in addition, the substance itself is very prone to decomposition, and is mixed with other bodies equally unstable and equally hard to detect, a degree of complexity is introduced into the investigation which makes it an almost hopeless task in the present state of chemical science.

Such are the perplexities under which the Water Analyst labours, and their careful consideration may serve to account for the wide differences of opinion on this important subject. It is much to be regretted that this uncertainty should exist, and it can only be hoped that in a short time a bright light (possibly by the aid of electricity) will illumine this almost untrodden ground of research.

The Author proposes to divide the subject as follows:—

1. The various ways in which water becomes contaminated.
2. The methods employed by analysts to detect and determine the extent of this contamination, with an opinion as to the probable value of the results obtained by the various methods.
3. The bearing of the results of biological and microscopic research on the question.
4. The adequacy or inadequacy of the proposed remedial measures, irrigation, chemical treatment, and filtration.

1. The various ways in which water becomes contaminated.

Immediately on the condensation and precipitation of the aqueous vapour of the atmosphere as rain, the liquid dissolves more or less of every substance with which it comes in contact. Oxygen, nitrogen, carbonic acid, ammonia, and nitric acid can be detected, and these may be taken as normal constituents of rain falling on the surface of the earth or on the catchment reservoir of a town. It will also be always more or less contaminated with the excreta of animals, although reservoir-water will contract but an inappreciable amount of impurity from this source.

The next stage for consideration is rain-water in the form of springs. In addition to the above-mentioned bodies, spring-water contains various mineral substances dissolved from the strata through or over which it has passed, the majority if not the whole of which are innocuous in the quantities in which they exist in most specimens; together with a further amount of animal contamination, varying in nature and quantity with the character of the area, as to population and agriculture, in which the springs occur. In remote country districts the contamination of the water up to this point is very slight.

In the next stage, the rivers, there is an enormous increase of contamination. Nor is this to be wondered at, considering that rivers are the natural drains of the country, into which every particle of rain falling within their watersheds (except that evaporated from the surface) ultimately finds its way, with everything which it is capable of dissolving or suspending. Highly manured arable land, pastures with their thousands of cattle and sheep, mills, factories, village cesspools, and, lastly, town sewers, all contribute their quota of foul water; in some cases to such an extent that the river becomes an open sewer in which no fish can live, and the exhalations from which, especially in hot climates, spread fever and death around.

The remaining sources of water to be considered are wells. In country places these may be uncontaminated, but in most cases it is far otherwise, owing to the utter want of foresight in the sanitary arrangements, the cesspool being frequently close to (and of course above the level of the water in) the well. With regard to wells in towns provided with a deep sewerage system, they are generally dry, fortunately for their owners; on the other hand, if the town be provided only with cesspools, the ground is so saturated with sewage-matter from the latter that the water is totally unfit for use.

2. Having thus considered the various sources of water supply, and the nature and amount of contamination to which each is liable, the second division of the subject follows—"the methods employed by analysts to detect and determine the extent of the contamination."

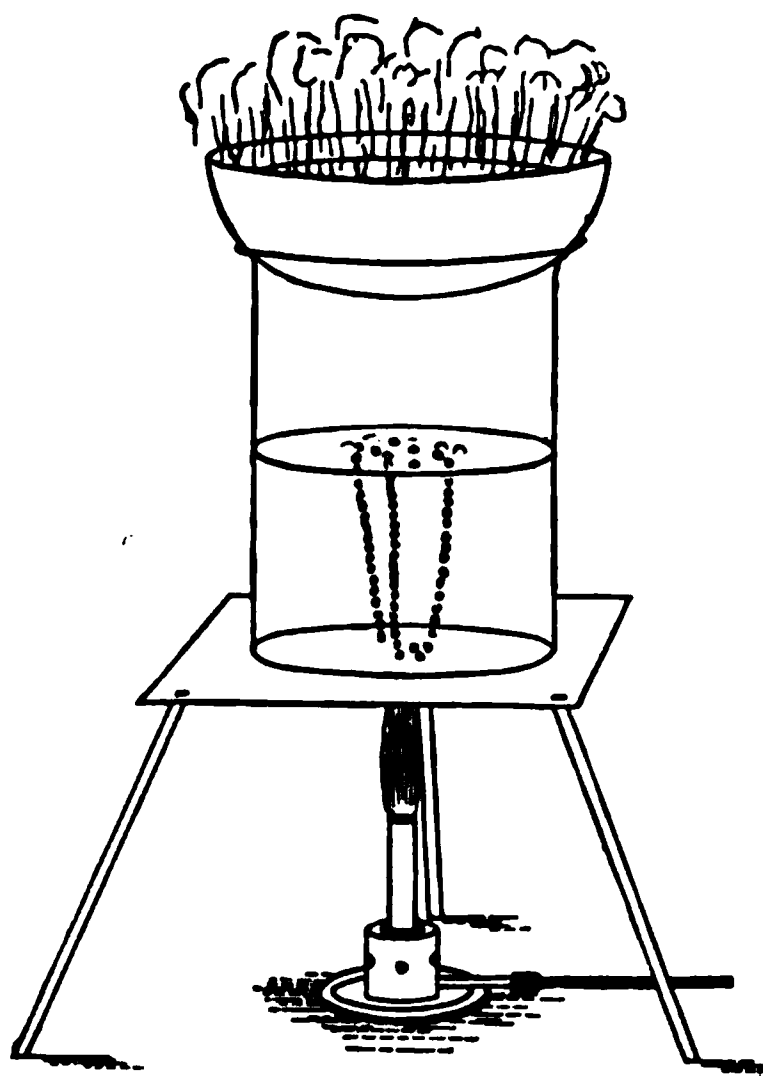
The mineral constituents may at once be dismissed, as their determination is a very simple matter; and unless they exist in enormous excess, without doubt they are practically harmless. The organic substances in solution and suspension are the most important, on account of their dangerous nature, and, unfortunately, they are the ones with which the chemist is least able to deal. As yet he has been compelled to be content with the examination and estimation of the products of their decomposition—ammonia and nitrous and nitric acids—or with the determination of one or two of their constituent elements (carbon and nitrogen). Urine *per se* is by no means a difficult substance to detect and analyse; but the examination of water containing one-hundredth or one-thousandth part of urine, a week or two old, is a very different matter. So also with the solid excreta of animals on the one hand, and the same suspended in minute quantities in water on the other. In the present state of analytical

chemistry it is impossible to detect either the one or the other these highly diluted forms. Common salt is abundant in urine but so it is in many soils, and therefore is generally found in water; and as it is impossible to distinguish between that derived from the land and the same substance contained in sewage, the fact of its presence or absence in a sample of water is not of much importance.

Then, again, rain contains ammonia and nitric acid (if not a nitrous acid), and it becomes impracticable to detect whether these substances, when found in water, are derived from the decomposition of organic matter with which the water has been contaminated, or have simply been dissolved from the atmosphere during the rain in falling.

(a) The oldest process for the investigation of the organic matter in potable water is by the incineration of the solid matter left on evaporation of the sample, and it has the great advantage of simplicity. A measured quantity having been evaporated

FIG. 1.



Process (a). Platinum Dish in Water Bath.

to dryness, the residual solid matter is weighed and heated finally to bright redness. The evaporation is usually conducted in a platinum dish in a water-bath (Fig. 1), by which means loss by ebullition is avoided. The residue, after weighing, is heated to redness in the dish over a Bunsen flame. By this process organic matter is burnt away, carbonic acid, nitrogen, &c. being given off. At the same time any carbonate of lime or magnesia is decomposed, carbonic acid being expelled. To correct the error thus introduced, the ignited mass is moistened with a solution of carbonate of ammonia, which means the quick-lime

left again takes up carbonic acid equal in amount to that expelled. It was generally assumed that the magnesia did the same, but this is found not to be the case. The excess of carbonate of ammonia having been driven off by a gentle heat, the

dish, with its contents, is again weighed, and the difference, amounting usually to from 2 to 6 grains per gallon, was assumed to represent the quantity of organic matter present. Unfortunately, many water residues show a gain of weight by this treatment, and it has been conclusively proved that it is impossible to measure the quantity of organic matter by this method; but as it affords useful hints as to its nature, it cannot well be dispensed with. For instance, if, on heating, the dry residue blackens, and an offensive smell (especially one of burnt hair) is given off, the existence of nitrogenous animal substances in the water is conclusive, and in nine cases out of ten these substances are animal excreta of recent origin. If, on the other hand, there be little or no liberation of carbon (and consequent blackening when the water residue is heated), and if sparks be noticed, or the peculiar smell of burning touch-paper be perceived, organic matter and nitrates or nitrites are indicated, by the mutual reactions of which, at high temperatures, these effects are produced. From this it can be inferred that part of the organic matter has been oxidised and converted into the harmless salts of nitric or nitrous acid, while another portion remains undestroyed in the water.

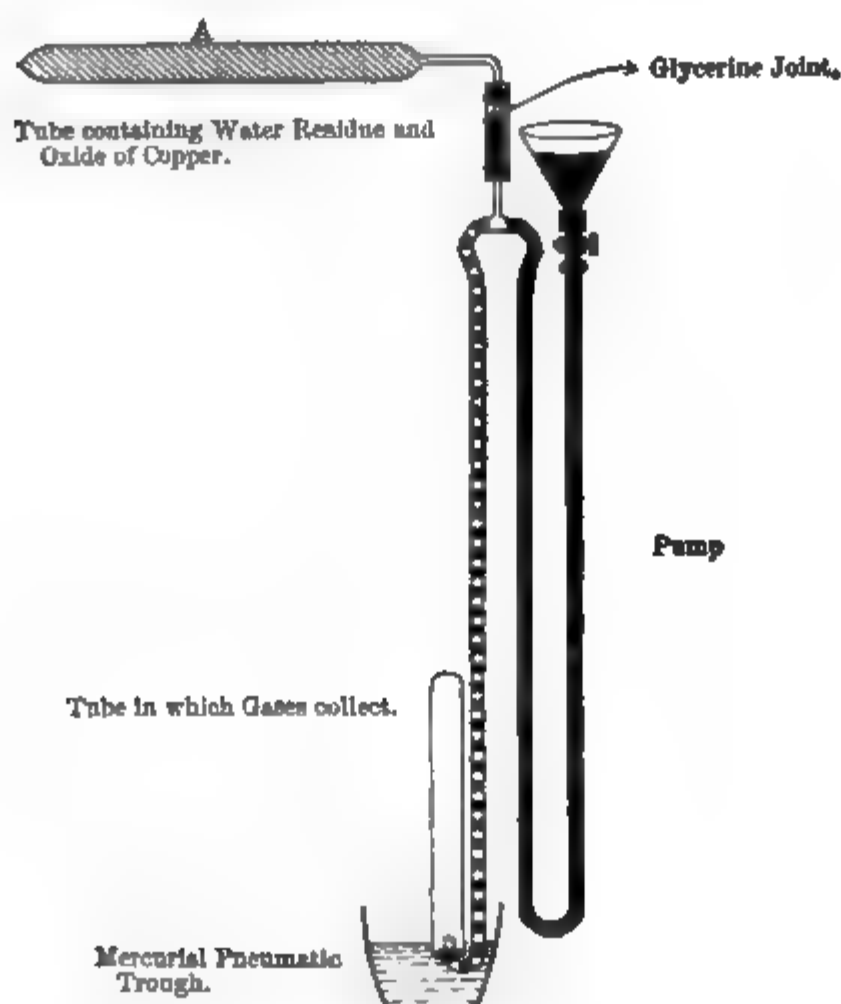
Again, if the blackening produced by ignition speedily disappear by contact with the air, the organic substance from which the carbon was liberated was most probably of vegetable origin, and therefore less dangerous to the animal economy. If, on the other hand, the carbon burns off very slowly, it was probably derived from animal substances, which are the most objectionable forms of organic impurities.

It will be as well to point out at once, however, that there is a fundamental objection to the process in the very fact of the evaporation of the water. There is no evidence to show that such unstable bodies are not partially, or in some cases totally, destroyed during the process. Indeed, with one of them (urea) this is known to be the case.

(b) The process introduced by Drs. Frankland and Armstrong is open to the same objection, a prolonged evaporation of the water, and although this is effected at a temperature below the boiling point, it is complicated, and in all probability rendered far more destructive to the organic matter which it has been devised to estimate, by the presence of mineral acids during the evaporation. The residual solid matter is submitted to ultimate organic analysis, by which the amount of nitrogen and carbon is computed. The process is as follows:—The water residue is intimately mixed with

oxide of copper, and transferred to a tube, $\frac{1}{2}$ -inch in diameter 12 or 15 inches long, which is then completely exhausted of a Sprengel pump (Fig. 2). The tube, with its contents, is

FIG. 2.



Process (b). Glass Combustion Tube and Mercury Pump.

to bright redness, till no more gas is evolved, and the product of the reaction (consisting of steam, nitrogen, and carbonic acid) is pumped out into a tube full of mercury standing in a pneumatic trough. The steam is condensed, but the nitrogen and carbonic acid are separated and measured, and from the number of cubic inches of each gas obtained, the weights of nitrogen and of carbon (and from that, of the carbon itself) are easily deduced. At a red heat, oxide of copper decomposes all organic substances, animal or vegetable, transforming their carbon into carbonic acid gas, their hydrogen into aqueous vapour, while the nitrogen is evolved in the free state, also as gas. The presence of mineral matter during the evaporation is necessary to drive off the carbonic acid, usually a carbonate of lime or magnesia, which, if it were not previously got rid of, would be expelled by the red heat and

with the carbonic acid formed from the organic matter, so causing an error. The nitrogen and carbonic acid collected are measured over mercury; the carbonic acid is then absorbed by a solution of potash, and the gas left, which is nitrogen, is measured, the difference being the carbonic acid.

Having thus obtained the weights of carbon and of nitrogen existing as organic matter in a certain volume of the water, or rather that portion of the organic matter which has not been decomposed by the prolonged heating with mineral acid, the quality of the sample is inferred from their amount, and from the ratio which they bear to one another, it being assumed that the greater the ratio of nitrogen to carbon, the more highly organised, and therefore the more dangerous, is the organic impurity. A very little thought, however, will suffice to show that the information thus obtained is only of the most general character. Assuming, then, that a high ratio of nitrogen to carbon is characteristic of the organic matter in a dangerously polluted water, if a further pollution by organic substances, in which the nitrogen-carbon ratio is small, take place, the doubly-fouled water would be returned as the less dangerous. This example shows the weak point of the process, or rather of the deductions made from the data furnished by it, namely, the application to a mixture of substances (the organic impurities of water) of reasoning which can, properly speaking, only be applied to the case of a single substance.

(c) A process which has found much favour amongst analytical chemists is the so-called albumenoid ammonia method. It is assumed that the nitrogenous organic impurities in water are the most dangerous, which is probably the case, and the process professes to estimate the quantity of these substances, by determining the amount of ammonia produced by their decomposition when boiled with an alkaline solution of permanganate of potash. A glass retort and Liebig's condenser are used, the amount of ammonia formed being estimated in the distillate. This is effected by making up solutions of ammonia of different known strengths, and observing which of them gives a brown coloration of the same intensity as the sample under trial, when mixed with a solution of iodide of mercury and potassium.

No previous evaporation of the water is necessary, which is undoubtedly a great advantage over the first two processes; but inasmuch as this method is only an imperfect ultimate analysis, even less knowledge is obtained than by the second method, though this has the great advantages of ease of manipulation

and rapidity, the results being in all probability of equal value for practical purposes.

(d) The last to be considered is the permanganate process, in which the amount of permanganate of potash required to oxidise the organic matter is ascertained. This is supposed to be an index of the quantity of organic matter in the water, and it would be so if only one form were present; but inasmuch as there may be dozens of different substances in solution or suspension, some hurtful, some harmless, some susceptible of much oxidation, some almost, or even totally, unacted upon by permanganate (and so far as is known the most dangerous may consume the least oxygen, or none at all), it is obvious that this method also will not afford results the accuracy and reliability of which are above suspicion.

The estimation of the ammonia, nitric, and nitrous acids in water, is a simple problem in mineral analysis, of which it will be unnecessary to treat in detail.

Having briefly reviewed the advantages and defects of the various processes for estimating the nature and the amount of the organic contaminations of potable water, it seems impossible to come to any other conclusion than that the subject is as yet beyond the scope of analytical chemistry. Even granting that the assumptions of the advocates of the different processes are correct, it is evident that their deductions are illogical, reasoning fit for a single substance only being applied to a mixture of substances.

As regards inorganic analysis the processes can be checked by experimenting on weighed quantities of pure substance purposely mixed with other bodies. If the same amount is recovered (within the small limits of errors of experiment), the process is evidently a reliable one; but with the impurities of water this is impossible, and the information afforded by the methods now in use is of the vaguest and most general character, so far as the wholesomeness or the reverse of a given sample is concerned, although by one of them (b) it is possible to determine the minimum amount of contamination which has taken place since the water was precipitated as rain. For this purpose the whole of the nitrogen existing in any form in the water is determined, but this does not include free or gaseous nitrogen dissolved from the atmosphere, which is expelled in the preliminary evaporation, and therefore does not affect the results, viz.:—

Nitrogen in the form of ammonia.

“	“	organic matter.
“	“	nitric and nitrous acid.

Deducting from this total the average amount of nitrogen in the form of ammonia which exists in rain as it falls, the residue is the minimum quantity which the water has acquired from animal and vegetable contamination. It is not necessarily the total quantity acquired, because some may have been abstracted by growing plants, &c.

No definite impression is conveyed to the mind by the statement that there are in a sample of water so many parts per 100,000 of nitrogen, derived from animal and vegetable detritus. A standard of contamination therefore becomes desirable, and the one which has been proposed is the amount of nitrogen per 100,000 parts of average filtered London sewage. By simple proportion it is then easy to calculate the degree of contamination of any water; that is as if 100,000 parts of pure water had been mixed with so many parts of London sewage.

It must be borne in mind, however, that no distinction is made in this case between nitrogen present as organic compounds of more or less dangerous character, and nitrogen existing in the harmless inorganic salts of ammonia, nitrous and nitric acids. This latter form of nitrogen represents more or less originally dangerous organic impurities, which have been gradually resolved by oxidation or fermentation into the inorganic forms. Consequently a deep well-water, *e.g.* from the Chalk, may be returned with perfect accuracy as having received as much or more "previous sewage contamination" than a shallow well or river, and yet in the former case the water may be absolutely innocuous (all its organic impurities having been destroyed by oxidation in the pores of the Chalk), whereas the well or river water, with its recent contamination, may be quite the reverse.

The first stage in the oxidation of nitrogenous organic matter is the production therefrom of ammonia, which by further oxidation is converted into nitrous or nitric acid.

3. Chemists being powerless to help the sanitarian in discriminating between wholesome and unwholesome water, it seems essential to consider what can be done by microscopists and biologists. In the first place it is an ascertained fact, proved beyond the possibility of doubt, that mere dilution, how far soever it be carried, does not render inoperative the specific action of living germs, and so marvellous is the rapidity of reproduction of low forms of life, that if the environment or conditions are favourable to their growth, it matters little whether the liquid is stocked with ten or with ten thousand at the commencement. In a few days there will be as many as can exist, the only

difference being that the sample which received most of the contaminating liquid will arrive at the maximum a few hours before the other. There can be little doubt but that the same thing occurs in the case of the human subject. Provided the individual is sufficiently weakly or unhealthy, it is of small importance whether he receive 1,000 or 1,000,000 parts of infectious matter (whether in the form of organised germs or not is immaterial), and consequently 1 part of infected sewage containing the dejecta of persons suffering from zymotic disease mixed with 1,000,000 parts of water will be nearly as dangerous to him as 1 part per 1,000. Of course the less contaminated water would probably not affect a person in more robust health who might succumb to the use of the highly contaminated sample; but what the Author wishes to insist upon is that it will be impossible to banish zymotic disease from a town whose water-supply has been contaminated with the dejecta of patients suffering from that disease. The very weakly will contract it from the almost inappreciable amount of infection contained in the water, and from them it will spread to those who have resisted the poison in its diluted state.

Secondly, the germs which cause or accompany disease are endowed with the most persistent vitality, and are capable of withstanding heat, cold, moisture, drought, and even chemical agents, to a marvellous extent. So difficult is it to destroy them that for many years the now exploded doctrine of spontaneous generation found talented supporters, who relied on their own carefully conducted experiments to prove the theory, all which experiments were subsequently found to have been rendered illusory by the astounding vitality of these low forms of life.

Bearing in mind, then, the influence, or rather the absence of appreciable influence, of mere dilution, and the difficulty with which infectious matter is destroyed, the conclusion that once-contaminated water never purifies itself sufficiently to be safe for dietetic purposes becomes inevitable; and as chemical analysis fails to give reliable evidence as to its fitness or the reverse, the Author believes that the only safe test of the wholesomeness of a given water is by tracing it to its source, and ascertaining that no objectionable impurities gain access to it.

This will at once condemn all rivers flowing through a populous country; and if it be considered that a river is the natural drain of a district into which everything soluble or suspensible in water ultimately finds its way, it will not be a matter of wonder that this should be the case. No Conservancy Board can keep pollution out

of a river; it must receive all the rain falling within the limits of its watershed (excepting, of course, that which is evaporated), together with the overflowings of cesspools and the sewage of towns within the same area. It is part of the great circulatory system of the earth which it is vain for man to attempt to control.

This being so, it is evident that rivers, except near their source, can only afford polluted water, and a problem utterly insoluble by man is presented, viz. the purification of foul water on a large scale. The chemist can do it in the laboratory, but only by adopting a similar process to that by which it is effected in Nature—fixation of the ammonia in the soil or its oxidation to nitric acid, followed by distillation by the heat of the sun. Take, for example, the case of a river; with a town of 50,000 inhabitants on its banks. If supplied with water at high pressure and sewered, the amount of foul water discharged into the river will be about 1,000,000 gallons daily, irrespective of the rainfall, which will bring with it the washings of the streets, &c. Taking the total flow of the river at 500,000,000 gallons, and supposing that the water is perfectly pure when it reaches the town, there will be a mixture of 1 part of sewage in 500 parts of clean water, for the inhabitants of the next town to drink. Take now an infected liquid and add 1 part to 500 or even to 500,000 parts of liquid susceptible of infection. The mixture will swarm with low organisms and become putrid in a few days, provided only the conditions are favourable. And what may be expected to happen to the unfortunate inhabitants of the lower town? Simply this, that the strong and healthy will have sufficient vitality to throw off the poison, but the weak and sickly will succumb, inoculated by the dejecta of zymotic patients in the upper town. Such a state of things seems hardly possible in a civilised community.

The above is no fanciful picture. The experiment was tried on the inhabitants of a town in Surrey, unwittingly it is true, but on that account the result is all the more reliable. An epidemic broke out, and the consequent investigation revealed the cause in all its loathsome details. Fortunately for mankind at large the relation in this case between cause and effect was distinctly traceable, but in the great majority of cases this is out of the question.

There is not the least evidence to show that foul water is rendered wholesome by flowing 50 or 100 miles, indeed all experiments point in the opposite direction, on account of the persistent vitality of the organisms which accompany zymotic disease, and

of the utter failure of dilution to disarm these potent germs corruption and death.

4. The possibility of abating these evils, otherwise than by radical change, will now be referred to.

It is often asserted that as the sewage of towns is "treated" by chemical agents before being passed into the river, the previous objections do not hold good. But inasmuch as most of the solid matters are unaffected by the process, and in view of the great vitality of the low organisms, it is open to doubt if the latter are destroyed by the agents used. Even the irrigation process, the most natural, simple, and effective where the locality is suitable, is liable to the serious objection that part of the sewage may flow direct to the river through accidental channels, without filtration through the soil.

Putting, however, all this aside, those who are practically acquainted with the subject are perfectly aware that no sewerage system yet carried out (even though its cost be reckoned by millions sterling) can cope with storm-water. As a necessary consequence the by-pass must be opened, the sewage allowed to flow direct into the stream, and the inhabitants of the town below regaled with a more than ordinarily filthy beverage for the next few days. This again is no fanciful statement; it can be seen in operation more or less frequently all over the country.

Filtration is another remedy put forward as infallible by those who have not grasped the subject. How can filtration affect substances dissolved in water? and as for the minute organisms found in putrescent bodies, they could pass a hundred or a thousand abreast through the interstitial spaces of ordinary sand, as used for this purpose.

In the Author's opinion, and probably also in that of most people who have carefully and dispassionately considered the subject, the purification of diluted sewage to a sufficient extent to render it safe for dietetic purposes is an impossibility, putting sentiment aside altogether. Indeed, the mere idea of a community drinking the diluted sewage of another would be almost inconceivable, were it not unfortunately a fact, and one with which the alarming increase of cancerous diseases of the stomach and intestines is, in all probability, intimately connected.

The present methods of water analysis are quite capable of showing if contamination has taken place, at all events in the majority of cases; but as to whether that contamination is injurious to health or not, there is no knowledge, and consequent

the only safe course in the Author's opinion is to reject all sources of supply unless they stand the test of absolute freedom from organic substances so far as can be ascertained; or preferably, of rigid examination by tracing the water from the time it falls to the earth as rain till it enters the reservoir or well.

The Paper is accompanied by several diagrams, from which the woodcuts have been engraved.

Discussion.

Mr. Latham. Mr. BALDWIN LATHAM said he concurred with the Author in the conclusion that the chemist was not able to determine whether water was wholesome or not. He used the word "wholesome," whereas the chemist used the word "pure." The purity of the chemist simply meant that he compared water with a given standard, and if it came up to that standard he said it was pure, and if not it was impure. But the impure water of the chemist was not always unwholesome water, nor was the pure water of the chemist always wholesome. He differed from the Author, however, in regard to some points, as, for instance, the river exhalations were injurious, spreading fever and death. Mr. Latham maintained, on the contrary, that there was no evidence to show that exhalations from polluted rivers had proved to be detrimental to health. Every authority agreed upon the point that malaria was never extricated from water surfaces, and in malarious countries it was not until the water had disappeared that malaria became manifest. In this country there were sufficient examples to show that the exhalations from foul rivers were not unwholesome. He might instance the case of the year 1854 before the sewage was discharged lower down the Thames, when the foul tide flowed through London. It was a year of drought and great stench prevailed along the banks of the river, but the mortality tables did not indicate that the districts bordering upon the Thames had in any way suffered. He might quote other towns, like Norwich, where the river Wensum was formerly polluted in a similar way to the Thames, thereby causing a great nuisance to the villages below, yet not one of them had suffered in health from the exhalations. He could not agree with the Author that there was no evidence to show that foul water was rendered wholesome by flowing 50 or 100 miles, and that diluted sewage (meaning, he presumed, water contaminated by sewage) could never be made safe for dietetic purposes. Nor could he agree with the statement as to storm-water overflows, but as that was no part of the question under discussion he would not dwell upon it. The subject of the Paper was one of considerable importance to those engaged in questions of water-supply, he regarded the future improvement of the sanitary condition of the country as being almost entirely dependent upon attention which must be paid to the selection of water-supply and the means to be adopted for effecting the purification of water.

At present, if engineers were to take the dictum of some chemists, Mr. Latham it was quite clear that there was no water-supply fit for use. In the sixth report of the Rivers Pollution Commission it was stated "that it is in vain to look to the atmosphere for a supply of water pure enough for dietetic purposes." Now, as all sources of water-supply were due to atmospheric causes, and as the Author had stated that it was useless to look for purification by any mode which would be adopted by the engineer, such as filtration or percolation (because the germs, he said, could pass a thousand abreast through a filter), therefore if the rain-water was impure at its source how could it ever be purified? Indeed, if the water-supply of the country were in such a lamentable condition, the wonder was that there was any one living to describe the state of things. The chemist could not discover what were the dangerous impurities in water. In order to supply a deficiency in the Paper, or the furnishing of facts to substantiate the proposition put forward, he would read an answer given to a question by Dr. E. Frankland in the Middlesborough water case. Q. 5,052. "And do you think it most unsafe to supply a large population from water which has been impregnated with the excreta of patients suffering from various diseases?—I do; although chemical analysis may fail to detect anything unusual in the water, because I have myself mixed 1 volume of the dejection of a patient dying of cholera with 1,000 volumes of good water, and have submitted it to analysis, and have been unable to detect anything unusual in the water; chemical analysis is unable to detect these small quantities of morbid matter, which are calculated to transmit disease to people drinking the water." That was the opinion of one of the most distinguished chemists of the day. With reference to the amount of contamination in water capable of producing disease, he would quote from a little book on "Potable Water,"¹ by Mr. Charles Ekin, F.C.S. Mr. Ekin stated, p. 15, "Waters which have undoubtedly given rise to typhoid fever have been found by the writer over and over again not to contain more than 0·05 part of albuminoid ammonia in 1,000,000, and which notwithstanding their containing a large excess of nitrates have been passed by analysts of undoubted ability as being fit for drinking purposes." In an outbreak of typhoid fever at Guildford in 1867, it was clearly shown, on analysing the water which was the supposed cause of the outbreak, that it was purer than other samples on

¹ Vide "Potable water, how to form a judgment on the suitableness of water for drinking purposes." 1890.

r. Latham. which no suspicion rested. In all the calculations of the chemist it appeared to be only a question of degree; they could neither distinguish between the matters which were found in the water, nor the source from which they were derived. If a certain quantity of organic matter, whether sewage or the "germs" of disease, was mixed in the proportion of 1 part to 4 parts of pure water the chemist would call the mixture good water. On the 29th of November, 1875, when an epidemic of typhoid fever was rife in Croydon, there were great suspicions respecting the quality of the water supply. The level of the water in the well at the waterworks was lowered by pumping and three samples of water were collected as they trickled into the well. They were submitted to Professor Wanklyn, who gave the amount of albuminoid ammonia in the respective samples as 0·14, 0·26, 0·22, per million parts. He stated that two samples were highly charged with sewage and that the other sample was not pure; but in the well the water contained 0·04 of albuminoid ammonia, and he added that that was water of the purest class. Thus, from the examination of the chemist, it appeared that it was quite possible to mix water which the chemist condemned as impure with that which was pure, and the result would be that the water came out as belonging to the purest class. As to the question of albuminoid ammonia being the means of showing whether water was wholesome or not, he might mention that about the end of the year 1880 the chairman of the Nantwich Local Board of Health told him that the Medical Officer of Health of Mid-Cheshire had condemned the public water-supply of the town as totally unfit for domestic use. The supply was taken from a natural lake called "Baddiley Mere," and was brought a distance of $4\frac{1}{2}$ miles by gravitation into the town. The authorities had only power to draw off to a certain depth the top-water. It appeared, from an examination in October 1880, that the amount of free ammonia was 0·21, and of albuminoid ammonia 0·44 in a million parts in the unfiltered town water, but after efficient filtration the amount of free ammonia was 0·08, and of albuminoid ammonia 0·38. The chemist stated in regard to it, "Organic matter in great excess, rendering water dangerous and unwholesome; the contamination not recent; filtration of little use." In the month of November a second analysis was made, and the results were a little better. The filtered water showed 0·32 part of albuminoid ammonia instead of 0·38, and the remark by the chemist was "the least said about these the better." The report also contained the analyses of the well-waters in use in the

town, which were, without exception, very unsatisfactory from the Mr. Latham chemist's point of view. He then inquired of the Chairman of the Local Board what was the state of health in the town; he was informed that it was never better, and he therefore advised the Chairman of the Board that as long as the public health was so satisfactory to pay no attention to the alarming reports of the chemist. The Registrar-General had since issued four quarterly Reports on the health of the district, namely, for the fourth quarter of 1880 (embracing the period in question), and three quarters in 1881. During the year there had been one death from scarlet fever, two from diarrhoea, and one from fever, the population of the district at the census of 1881 being 11,192. The zymotic death-rate in the year was but 0·35 per thousand, or about one-tenth the zymotic death-rate of London in the same period, and was one of the lowest that it was possible to conceive in any district, and yet the district was supplied with "dangerous and unwholesome" water.

The following Table showed the relative amount of average impurity in the water-supplies of London, as ascertained by Dr. Frankland, together with the death-rates in each year. The investigation was begun in 1868, when the impurities in the

Year.	Proportion of organic impurity in Thames Water delivered in London.	Proportion of organic impurity present in Lee Water as delivered in London.	Proportion of organic impurity in Deep-well Water as delivered in London.	Annual death-rate of London per 1,000.	Death-rate of London from seven principal zymotic diseases per 1,000.	Death-rate of London from Fever per 1,000.
1868	1,000	484	254	23·5	4·82	0·78
1869	1,016	618	312	24·6	5·57	0·78
1870	795	550	246	24·1	5·19	0·63
1871	928	604	150	24·7	5·97	0·54
1872	1,243	819	221	21·4	3·84	0·41
1873	917	693	250	22·4	3·32	0·45
1874	933	583	287	22·4	3·29	0·46
1875	1,090	751	250	23·5	3·87	0·37
1876	903	562	246	22·0	3·56	0·33
1877	907	596	243	21·5	3·43	0·35
1878	1,056	747	323	23·0	4·05	0·37
1879	1,175	954	387	22·7	3·25	0·29
1880	1,263	1,143	393	21·6	3·64	0·24
Average.	1,013	708	273	22·9	4·14	0·46

r. Latham. Thames were called 1,000 parts. With that number the relative amount of impurity in other years and other sources of water-supply was compared. The numbers were proportional.

The highest annual death-rate, and the highest zymotic death-rate in London (1871), occurred when the impurities in the Thames and Lee were below the average, and the waters of the deep wells were freest from impurities. The high fever death-rate in 1868 occurred when the impurities in all the sources of water-supply were below the average. The lowest death-rate in London occurred in 1872, when the impurities in the Thames and Lee were above the average; and in 1880, when the death-rate was low, all the sources of water-supply contained impurities in excess. The zymotic death-rate of London was lowest in 1879, when all the sources of water-supply contained impurities above the average; and under similar circumstances the fever death-rate in London was lowest in 1880. In the year 1870 the waters of the Thames and Lee contained the least amount of impurity, yet in that year the death-rate was above the average. In the last three years there had been an excess of impurity in all sources of water-supply, yet during the same period the death-rate had steadily declined. He did not wish to impugn the character of the chemists; they were men of great honesty and ability, and they themselves confessed the things to which he had referred. Dr. Frankland had admitted that small quantities of morbid matter could not be detected by chemical analysis. But there was a vast amount of ignorance among the general public on the subject, and he had himself to combat it to a great extent in the case of investigations made at Croydon. Dr. M. F. Anderson, in a letter to the "Sanitary Record" of February 3rd, 1877, stated, with regard to the albuminoid ammonia process, that he had "never been able to obtain conclusive evidence that the dangerous elements of bad water are evolved as albuminoid ammonia"; and he added, "My observations tend rather to the belief that typhoid germs are easily oxidised, and do not yield up their nitrogen as ammonia, but as nitro-oxides." That rather went back to the question of previous sewage contamination, which seemed to be almost a phantom of the past, as it appeared to have been abandoned by its author; but he thought there was something in it, because it certainly showed the progressive impurities that took place in water. From the Report of the Royal Commission on Water-Supply, it was shown that in the district from Caterham to Croydon there was a very considerable increase in the previous sewage contamination; or a progressive degree of deterioration in

the water had taken place. Those who were conversant with the district would know that there must have been such deterioration because the valley was thickly populated; it had two waterworks in its upper part; it had no sewers whatever; all the water pumped passed through cesspools, and by a sort of circulating system all the impurity was carried back into the soil, and which flowed down the valley, and what was not used naturally found its outlet in the river Wandle. It was evident that in a valley of that kind there must be a natural deterioration; but unfortunately the chemists had never been able to find it, for although the previous sewage contamination had enormously increased, that counted for nothing with the chemist at the present day. In such a district, however, what might have been proved to be previous sewage contamination was very likely to become present sewage contamination of the most dangerous description. In the epidemic of fever in Croydon in 1875 the water had been analysed over and over again; but it was always pronounced to be water of the purest class; yet in that year one person in forty-two living in the Croydon water district suffered from typhoid fever as against one in eight hundred and nine in the district immediately outside, and in many instances the same sewers were used in common. Numerous investigations had taken place in connection with the subject, and he had himself inquired into it, feeling that it was an utter disgrace to the sanitary science of the day that those repeated epidemics in Croydon should escape detection. They had always been referred to the same cause—sewer gas; but he believed that he should be able, from the facts he had collected, to throw a very different light upon the subject. If repeated coincidences were tantamount to positive proof, he believed he should be able to show that certain meteorological conditions were connected with the outbreak of every one of those epidemics, which came into operation only at particular times. One thing was certain, that at all times the fever death-rate in Croydon was inversely proportionate to the quantity of water flowing from the district. The Author had stated that it was necessary to trace water to its source. But that had been the difficulty in Croydon. The late Dr. Letheby, who analysed the Croydon water, found it to be good; but that did not satisfy his mind, for he distinctly reported to the authorities of the Friends' school, by whom he had been called in, that the water-supply was dangerous by reason of its source in the centre of the town. Mr. Latham at one period held the same views as Dr. Buchanan, who reported on this outbreak in 1876, that fever was caused by sewer gas; but he had seen reason

r. Latham. to alter his opinion. The difficulty, however, had been to the water; but during the past year, not only had the movement of the subsoil water been traced, thanks to the ability of a chemist in the City, but Mr. Latham had been able to bring the matter under direct calculation, and to show the quantity of the immediate subsoil water getting into the Croydon wells. The case was that the wells furnishing the supply of water to the town had been sunk and bored into the porous soil, consisting of gravel and sand. They were lined with iron cylinders for a certain distance from the surface, and the subsoil water outside the wells was supposed to be shut out by the iron lining; yet when pumping was going on every fluctuation within the wells was discernible in the water outside. It had been stated by an eminent engineer that these fluctuations simply meant that there was a sympathy between the waters. Other theories had been advanced, one of which had been called the "band-box" theory. It was stated that when the water outside the well subsided, it did not flow into the well, but that it was like a tier of band-boxes, the bottom one might be out, but the top one would not come down. Then it had been referred to pulsations, or waves caused by the agitation of pumps. Fortunately, for the sake of science, on the occurrence of a high flow at Croydon, early in 1881, a communication was received from Mr. G. W. Wigner, that if Mr. Latham would collect the same water during the high-borne-flow he would be happy to investigate the matter from a chemical point of view. After the collection of the samples, Mr. Wigner wrote to him that it would be desirable as the next step, to trace the movement of the underground water by means of lithium. He saw at once that this was exactly what was required to ascertain whether or not there was a connection between the immediate subsoil-water outside the wells and the water within the wells, and if the fluctuations which had been observed were indicative of this connection. Before making the experiments, however, he put two questions to Mr. Latham, the first of which was whether the material was innocuous, to which the answer was, "perfectly innocuous," and the other whether small quantities of the material could be detected, to which Mr. Wigner answered, "Yes, $\frac{1}{300,000}$ part of a grain can be found in a gallon of water by spectrum analysis, but in no other way." Three experiments were made at various distances from the Croydon Water Works wells, and it had been shown that the lithia moved in all directions exactly at the same rate, into the wells, as the fluctuations of the water caused by pumping had been found to move. Lithia was therefore, a mode of readily detecting the movement of

It was admitted that the subsoil-water at Croydon was in direct communication with the sewers, and if it got into the wells, it was a source of danger. There were great difficulties in carrying out the investigation, because the lithia could only be detected by spectrum analysis. Again, when material of that kind was put into the soil, a portion of it remained, and was with difficulty got rid of, for when an acid salt had been put into a chalk soil, a portion of the acid combined with the chalk, and a less soluble salt of lithia remained in the soil. Investigations of this kind should only be carried out under the advice, and with the assistance of a chemist. He did not think that Nature had left mankind in the unguarded and unprotected state described by the Author, liable at any moment to have their lives jeopardised from impurities in water. There were means, no doubt, by which the very foulest water could be purified, and those means were more active in a river than in any other source of water-supply. He would refer to the statement of Mr. T. Hawksley, Past-President Inst. C.E., with reference to the outbreak of cholera in 1848-9, recorded in the report of the Commissioners of Water-Supply, that in those years cholera was epidemic at Bilston, Wolverhampton, or in the Black Country; and so violent was it that people encamped outside the towns. During the whole of that time the sewage of those infected places flowed into the Tame, and, after a course of 20 miles down the river, it was used for the water-supply of Birmingham, and there was no cholera in Birmingham. It was therefore clearly shown that by the simple flow of the water that distance the morbid elements had been destroyed. He might also refer to a more recent period, 1875-76, when typhoid fever was prevalent in Croydon, there being at least two thousand cases in those two years, during which time the whole of the sewage of the town was passed on to the farm at Beddington. There was a cluster of eighty houses lying between the farm and the Wandle, all inhabited, their only water-supply being from shallow wells, and the proximity of the application of the sewage upon the farm caused the water in these wells to fluctuate, yet the elements of disease were destroyed so that there was not a single case of typhoid in any one of those houses, or even in the valley down to Merton, containing a considerable number of inhabitants. There again it was shown that Nature had provided safeguards; and it was the duty of engineers to copy the examples of Nature, and to treat water in the way in which Nature treated it, in order that the foulest and most dangerous impurities might be destroyed or removed from it.

Dr. Tidy said, in discussing the question of water-supply, it Dr. Tidy.

Dr. Tidy. was important to grasp its many-sidedness. When it was desired to supply water to a town, various possible sources were selected, samples were sent to a chemist, whose duty it was to analyse them. It was not for the chemist however to say whether the water was pure or impure. To him, pure water was hydrogen and oxygen and nothing else. To him, 1 cubic inch of dissolved gas, or 1 grain of dissolved matter, were impurities. The chemist had only to state what was the composition of the water submitted. From the chemist it passed to the sanitarian, the medical man, whose view of the subject was essentially different from that of the chemist. When the analysis was in his hand, he had to ask himself if the water was likely to be a proper one for the supply of the town for which it was proposed. He could not experiment with the water, but he endeavoured to ascertain where waters of a similar kind had been supplied, and what had been the result. That was the medical aspect of the question. It then passed to the engineer. It had already been decided that the water was good, the engineer asked him, "Is there sufficient to supply the town, and are the conditions such that it can be delivered at a moderate cost?" That was the engineering aspect of the question. It was essential to the purpose to separate these three. In criticising the Paper, perhaps somewhat severely, he might be permitted to say that he had some experience in water analysis. Without reference to the past, during which he had been in practice for himself, he had, during the many years that he had assisted the late Dr. Letheby, made nearly four thousand analyses of water with his own hands; as a medical man he had also had something to do with the sanitary aspects of the question. He would not discuss the various processes of water analysis, which he had himself dealt with at considerable length elsewhere. The Author had stated that chemists were "powerless to help the sanitarian in discrimination between wholesome and unwholesome water" (p. 65). Dr. Tidy did not pretend to say that the chemist could do everything, but he maintained that, given a reliable analysis of water, the chemist or rather the sanitarian, was able to speak with almost unshaking certainty in bringing it to bear on the sanitary question. What were the means by which to arrive at a true chemical knowledge of the composition and properties of water? He admitted, with the Author, that the varieties of organic matter in potable water were somewhat numerous; chemists, therefore, could not conduct a water analysis with the same certainty as they could a quantitative analysis of a body, with the exact constitution and composition of which they were familiar; but considering

two out of the four processes described in the Paper, vastly different as they were in their action, closely agreed in their results, he thought the public might reasonably have some faith in these as a means for estimating the organic matter in potable water. As he had shown before the Chemical Society, with reference to nearly two thousand cases of water analysis treated by the combustion process of Dr. Frankland, and by what Dr. Tidy had called the oxygen and others the permanganate process, the actual results were as nearly as possible identical. A report would shortly be issued by himself, Dr. Odling, and Mr. Crookes, on London water. No fewer than three hundred waters had been examined by both these processes, and by means of a series of wave-diagrams it would be shown how closely they agreed in the story they had to tell. The Author's statement that the chemist was powerless to help the sanitarian was a very strange one, coming from a chemist. What were the reasons he assigned for this powerlessness? In the first place he stated that "it is an ascertained fact, proved beyond possibility of doubt, that mere dilution, how far soever it be carried, does not render inoperative the specific action of living germs" (p. 65). His second reason was that "the germs which cause or accompany disease are endowed with the most persistent vitality, and are capable of withstanding heat, cold, moisture, drought, and even chemical agents, to a marvellous extent" (p. 66). That was all very well, but where were the germs? In only three diseases, pig-typhoid, remittent fever, and splenic fever, had anything of that nature been detected. No such thing as a typhoid germ had been discovered. One could no more analyse a water for the germ of typhoid, than one could analyse the brain for an idea. Not only, however, did the Author speak of germs as though they were tangible, but he had fixed the conditions of the life of a thing the very existence of which had never been proved. As to wholesomeness, the Author expressed his belief that the only safe test was by tracing the water to its source. What source? He doubted whether there was a particle of water in creation that had not passed through an animal body once or oftener. For himself, looking at the subject as a medical man and as a chemist, he believed the true test was not what the water was miles off, but what it was at the place at which it was proposed to be taken for supply. That was the practical method of testing it, and it was a method always adopted in other matters. Engineers should not trouble themselves about what the water was 50 miles off, or fifty years ago, but consider what it was at the time and

Dr. Tidy. the place where it was proposed to take it. The Author naturally with his views, condemned all rivers. He did not mince the matter, but said, "This will at once condemn all rivers flowing through a populous country" (p. 66). And he added, by way of illustration, "Take, for example, the case of a river with a town of 50,000 inhabitants on its banks. If supplied with water at high pressure and sewered, the amount of foul water discharged into the river will be about 1,000,000 gallons daily, irrespective of the rain fall, which will bring with it the washings of the streets, &c. Taking the total flow of the river at 500,000,000 gallons, and supposing that the water is perfectly pure when it reaches the town, there will be a mixture of 1 part of sewage in 500 parts of clean water, for the inhabitants of the next town to drink. Take now an infected liquid and add 1 part to 500, or even to 500,000 parts of liquid susceptible of infection. The mixture will swarm with low organisms and become putrid in a few days, provided only the conditions are favourable" (p. 67). Then he asked, "What may be expected to happen to the unfortunate inhabitants of the lower town? Simply this, that the strong and healthy will have sufficient vitality to throw off the poison, but the weak and sickly will succumb, inoculated by the dejecta of zymotic patients in the upper town." "The above," said the Author, "is no fanciful picture." Fanciful was not the word for it, and he hardly knew a word to express it, but certainly a more far-fetched picture, a more unbridled effort of the imagination, he had never come across. He wished to ask the Author to explain how it was that, in the case of towns affected with cholera on the banks of rivers, having regard to the period at which the outbreak of cholera occurred in those towns, the disease had invariably gone up the river and not down. He challenged the Author to produce a case in which the passage of cholera had been without a break down a river. The only case given in the Paper of injury from river-water was one in which the experiment of drinking polluted water had been tried on the inhabitants of a town in Surrey. He thought he knew the town to which the Author referred, and if he was right in his presumption, the case was one in which he had been himself consulted professionally, and he believed also Dr. Frankland. They had both written a report, and he was prepared to show, if necessary, that the illustration in question had nothing whatever to do with the subject. The Author had further stated that there was in the least evidence to show that foul water was rendered wholesome by flowing 50 or 100 miles. Dr. Tidy maintained that a distance

of 10 miles was sufficient for the self-purification of water under Dr. Tidy's proper conditions. A few weeks ago Dr. Dupré and himself had seen a wonderful illustration of the self-purification of water within a very much shorter distance. Turning to the sanitary aspect of the question, he would remind the members that in England there was a large number of towns supplied with well-water, and a large number supplied with river-water. He had taken the death statistics for ten years of thirty-six of the largest towns in England, eighteen being supplied by deep well-water, and eighteen by river-water. The eighteen towns supplied by well-water had a population of 889,340, and the eighteen towns supplied by river-water had a population of 911,742. The average death-rate of the towns supplied by wells was 22·72 per thousand, and the average death-rate of the towns supplied by river-water was 22·66 per thousand. In fever and some other diseases there was (except in certain cases that could have nothing to do with the water) a decided advantage on the side of rivers. It might be said that he had taken a number of towns indiscriminately and mixed them up together. To meet that observation he had examined the death statistics of London, as Mr. Baldwin Latham had done. He had gone carefully over Mr. Latham's figures, brought them down to the latest date, and elaborated them somewhat more fully. London was supplied by eight companies, five of which derived their supply from the Thames, one from the Lee entirely, and one from the Lee and from wells (the New River Company), and lastly, one that derived its supply exclusively from deep wells in the Chalk. The death-rate for ten years of parts supplied by river-water was 21·57, whilst that of the places supplied by deep chalk wells was 21·48. He had gone through the various diseases, and had found that while certain diseases, such as croup (which he thought could scarcely be traced to water), appeared to be a little more prevalent in the river districts, certain other zymotic diseases were somewhat in excess in the districts supplied by wells. It had been proved before the Duke of Richmond's Commission by the experiments of Dr. Frankland and Dr. Odling jointly, and these experiments had been since repeated, that at Hampton the river contained if anything less organic matter than the water at Lechlade, where the Thames first assumed the condition of a river. That water purified itself in a running river he was as certain of as he was of his own existence. And this self-purification was effected first by the process of subsidence, the solid matter in the water being carried down ; secondly,

Dr. Tidy. by the process of oxidation (the oxygen being partly derived doubt, from the air, and partly from plant life); thirdly, by action of fish. He had no doubt upon that point, and he was with a knowledge of many of the important rivers in England and Ireland. In conclusion, he desired to ask the Author a few questions. First, admitting the complexity of the organic matter in potable water, and that the true test of the value of different processes for its estimation was consistency in their results, had the Author ever attempted to prove or disprove such consistency; and, if so, could he favour the Institution with details of those experiments? Secondly, admitting the theory of rivers being such important agents in spreading disease, would he explain how it was that in outbreaks of cholera where towns have been affected along the banks of a river, the order of attack has been invariably up the river, and not down? Thirdly, would he explain how it was that towns supplied with river-water show no greater general or zymotic death-rate than towns supplied with deep well-water; or if that was not true, would he bring forward facts to contradict it? Would he explain, further, how it was that in London the parts supplied by the Kent Water Company show an almost identical general and zymotic death-rate with those supplied by the waters of the Thames and the Lee? Fourthly, admitting that there might be germs in running water, could he adduce any evidence to show that under natural conditions of flow and contact with oxygen they were not amenable to the same laws as organic matter generally? He would only say that if the chemist desired to gain the respect of the engineer or of the sanitarian, he must not indulge in far-fetched fanciful theories or hypotheses, but confine himself strictly to the arena of facts.

Dr. THUDICHUM. Dr. THUDICHUM said when important questions were concealed and one had a strong conviction to state, it was not easy to find a form in which to make that conviction acceptable. Nevertheless he hoped to make himself intelligible on some of the main points which he desired to illustrate. He congratulated the Author for having made on the whole a clear, succinct, and practical statement. No doubt it required on his part a great deal of courage as a chemist to come forward and tell his brother chemists that they were groping in the dark, and that their analyses were valueless. If chemical analyses of waters were to be discredited Dr. Thudichum would feel much regret; but there was a great deal of truth in what the Author had said. It had been suggested by Dr. Tidy that he had latterly come to the conviction

Dr. Frankland's analysis of water was as good as his own. If the Dr. Thudich members had been present at the meetings of the Chemical Society when that matter was discussed, they could hardly have believed what had since taken place. Neither having convinced the other as to the uselessness of his particular mode of analysis, they at last became friends, and said to each other, "Your analysis is as good as mine; let us embrace and be friends." What did those analyses mean? They ascertained that a certain amount of organic matter was present in water intended to be drunk, but they showed no more. The organic matter, for example, contained in Thames water could not be shown to be noxious to health. Chemists had not shown at what particular concurrence of conditions they were to begin to consider water injurious which contained a certain amount of organic matter, and under what circumstances it was to be considered wholesome. Waters taken from sources like rivers always contained organic matter, because they were always flowing over large surfaces clothed by vegetation, living or dead, and under all circumstances there was a certain amount of dead, organic, vegetable matter present in watercourses. How innocent the organic matter of the river Thames was he had proved in this way. He had sent to the places where the water companies took their water, and caused to be collected a large amount of organic matter, carried it to his laboratory, infused it with distilled water, and allowed it to stand a certain number of hours. He then analysed it, and found what he expected, that this distilled water had assumed, with regard to organic matter, the properties of Thames water. He therefore maintained that the analysis of water, with reference to the quantity of organic matter contained in it was, hygienically speaking, of no value. The next point to which he desired to refer was the bearing of the results of biological and microscopic research on the subject under consideration. That led to the point on which the whole argument oscillated. Under what circumstances was water wholesome, and under what circumstances was it unwholesome? There might be waters which contained so much inorganic matter as to cause diarrhoea, but such waters would be so unpalatable that they would not be drunk. On the other hand, there might be waters perfectly clear and palatable in which the chemist would discover no appreciable amount of organic matter, and yet they would carry death wherever they were consumed. That was the biological aspect of the question, and in regard to that aspect microscopic art was just as impotent as chemical art to determine whether water was wholesome or not. Then what

udichum. test could be applied to ascertain the fact? There were various tests, some of which had been unpremeditated. For example, when in the East of London cholera swept along the river Lee and attacked twenty thousand persons, that was an experiment on a large scale. When again in the South of London two companies rivalled each other which should proceed in the most successful way to distribute cholera amongst their consumers, as in 1848 and 1854, other examples were made on a large scale. If another example was required, showing how water might be contaminated without microscopists discovering it, the case of the poisoning of Caterham Well might be taken, by means of which three hundred and fifty-two persons contracted typhoid fever, because a small amount of excrement from a sick person who was allowed to work in the well got mixed in the water. Under such circumstances it was necessary to see with an eye which was not microscopic, and to apply a certain argument which was not chemical, but which was hygienic or medical. Water might be bright and brilliant, and yet contain the germs of death in it. It was well known that things might have organs and a certain chemical composition, and yet not be visible to the eye. Take the case of a minute drop of blood; put it on a microscopic slide, and add water to it. All the corpuscles were before seen to be red, and their shapes were distinguishable, but after the addition of the water the colouring matter was withdrawn, and no power of the microscope could make them visible. Here was a case in which an organised body of the diameter of $\frac{1}{1000}$ of a millimetre could be rendered invisible, and how much more might that be the case with a body having perhaps not $\frac{1}{1000}$ part of the diameter of a blood corpuscle? He referred to those germs which in the last thirty years had been proved to exist as the causes of zymotic diseases. He would refer, as an illustration, to the germ of the fowl-cholera. It was as distinct a germ as could be made out, visible under the microscope, having spores, still minuter particles, which were to the bacterium as the seed was to the plant. If those germs were preserved for a certain time in a closed tube, a cloud would at first be seen, but as the oxygen in the tube was removed and consumed, the germs assumed a different shape and appearance; they were lost to sight altogether. How were they to be found out? Not by the microscope, not by chemistry, but by taking a needle and dipping it into the liquid, which was perfectly transparent, and then inserting it in the cutaneous tissue of the fowl, and in a few days the fowl would be dead. It

was impossible to experimentalise with water merely, so as to Dr. Thudich show whether it was wholesome or not. What then followed? What hygienists had always maintained, that water should be taken from natural sources which were neither contaminated nor contaminable, and those should be the only sources of drinking-water for communities and individuals. Could this proposal be carried out? Of course it could. In the neighbourhood of London, for example, taking a circuit of 30 miles, 100,000,000 gallons of spring-water could be found running every day, which would be amply sufficient to supply the culinary and drinking wants of London. In the neighbourhood of Hertford, for instance, there was a spring yielding 10,000,000 gallons a day. It ran into the river lee, and there would be no practical difficulty in taking it out of the river, and sending it direct to London, without allowing it to be contaminated by dung-boats and all the filth that accumulated in the river. The citizens of London, who first attempted to supply the city with water, did not go for river-water, but for spring-water, and it was for the conduction of spring-water to London that they got their first Act of Parliament. In like manner engineers should set about it now, everywhere getting all the spring-water they could to supply towns. They would find in every neighbourhood a sufficient supply to satisfy the public wants. London, of course, would require a double supply, according to the proposal worked out by Sir Joseph Bazalgette, Mr. Easton, and Sir F. J. Bramwell, a proposal which had his greatest admiration. It should not be imagined that because it was strange it was unparalleled. In fact an example might be found in a town having much more limited means than London. He held in his hand a report by the Government of Würtemberg on the public water-supply of that kingdom, a kingdom which he believed was at the head of civilisation in regard to that question. In the capital, Stuttgart, there were two supplies, one of common water for watering the streets, filling baths and flushing closets, and another for drinking and cooking. Numerous instances might be cited from that report of the care taken to supply even the lowest classes of the community. Even the villages on the highest mountains in the Rane Alb were supplied with excellent spring-water, to the extent of 60 litres per head per day. It was pumped to the height of 310 metres, and the pressure in the pipes was 75 atmospheres. If a small village of that kind could be supplied with pure spring-water, would not the richest town of the richest nation in the world be able to get the same security against disease? The dangers threatening were very great. Per-

haps not once in ten years would a river carry disease massive in its water, but if it did so once in a century it should be provided against. The water from the downs of Hampshire came filtered through hundreds of feet of chalk. It was of the greatest purity, cool, and having no organic contamination of any kind, and if it were taken through pipes to the consumer in London, under a system of constant supply, all danger would vanish; but if the towns continued to be supplied with water from rivers, there would certainly be, on some occasion or other, a failure of filtration, the introduction of disease, and a repetition of the fearful and melancholy lessons of the last thirty years, during which one hundred thousand people had been crippled, and not less than twenty thousand had died from poisoned water. With the qualifications he had mentioned he fully agreed with the Author, and thanked him for having afforded an opportunity of discussing an important question.

Mr. HOMERSHAM said for more than thirty years he had been in frequent communication, year by year, with analytical chemists and microscopists in respect to the examination of water from different sources, to make selections for the supply of water for drinking and domestic uses. Many of those men, some of them personal and intimate friends of his own, as Clark, Graham, Lankester, Miller, Newport, Ronalds, Thomson, and Ure, were no more. From frequent communication with these, and still more frequent communication with others who remained, and from experience gained in designing and carrying out various works for the supply of different towns and places with water for domestic use, not only in the United Kingdom, but on the Continent of Europe, and places more distant, he was perfectly familiar with what had been urged for and against waters derived from different sources. He made that statement to ask indulgence, in case he should appear to speak somewhat dramatically. With regard to the Paper, it appeared to him that the word "previous" in the title had been unnecessarily added. For practical purposes, the point to be determined was the amount of the quality of sewage or other present injurious contamination, if any, in water for potable and domestic uses. Such water should be (1) at all seasons clear, transparent, bright, and, when seen in large bulk, pure blue, that being the natural colour of uncontaminated water; (2) well aerated, holding in solution from 7 to 10 cubic inches of air per gallon, consisting of 2 or more cubic inches of oxygen and 6 of nitrogen; (3) it should have at its source a uniform temperature equal to the average of

climate for the year, which in this country varied but little from 50° Fahrenheit; (4) should be free from living organisms, vegetable and animal, and from all dead decomposing organic matter, and should not dissolve lead; (5) should hold only a moderate quantity of mineral matter in solution, and thus be soft and not deposit a coating of lime or magnesia when being boiled. On the subject of potable water, he thought it was very questionable whether many persons drank cold water from choice. Where it was drunk at all, it was among the lower classes who unfortunately could not help themselves. When boiled it was drunk to a large extent, as in tea and coffee, and it was very largely used in culinary operations, and it was important that water used for such purposes should be such as did not deposit fur in boilers or tea-kettles. Uncontaminated spring- or other water, derived from a considerable depth below the surface of the earth, was the only water that at its source had a normal even temperature at all seasons, summer and winter, and, as far as he knew, was also free from living organisms, vegetable and animal. It was also difficult to find any water but spring or subterranean that was at all seasons clear, transparent, bright, and when seen in large bulk, blue. Water derived from brooks or rivers, or from lakes, natural or artificial, varied in temperature at different seasons of the year, being comparatively warm in summer and cold in winter; it was more or less opaque, and when seen in bulk lacked the blue colour peculiar to uncontaminated spring-water; it had in solution in warm weather less oxygen gas than spring-water; it held partly in suspension and partly in solution, after rains in hot seasons, manure washed from land and droppings from animals; and it also abounded in life, vegetable and animal, and was liable to inoculation by means of drains with the virus of specific diseases, causing ill-health and often death to those who drank it. He agreed with the Author in thinking that when samples of water from different sources were submitted to mere chemical analyses, it frequently happened that the results gave very little clue to their wholesomeness, or the contrary. He said very little clue, because there could be no doubt that chemical analysis often did give some clue, but in other cases it gave none whatever. Chemical, and only chemical, analysis could be relied upon to determine the quantity and quality of the gaseous contents of the water, the mineral contents and consequent hardness. The brightness, colour and transparency of the water could be judged by the sight. Chemistry threw little light upon the nature, quantity, and quality of the organic

Mr. Home
sham.

r. Homer- matter that might be dissolved or mixed or lived in waters.
m. Supposing, and this was common with river, lake and other surface waters, a water to contain a large quantity of minute organisms, say several species of living plants and animals, and several hundreds of each species in half a gallon, the chemist boiled all those plants and animals with the water, and after evaporating the liquid he weighed the residue, and then subjected it to a process of cremation. As the small animals and plants were composed of more than 90 per cent. of water, the loss in weight of the residue after cremation must be multiplied by 10 at least to arrive at their weight when alive. As to the names, or peculiar forms or qualities, wholesomeness or unwholesomeness, of the plants and animals, chemistry, to use the words of the Author of the Paper, was "powerless to help the sanitarian." Knowing that, it had been his practice during the last thirty years to submit samples of water, not only to an analytical chemist, and thus obtain all the assistance that could be had from chemical science, but to submit also samples to a competent microscopist and medical man well acquainted with the forms, names, habits, and other properties of the animal and vegetable organisms pervading many waters. The practical importance of such microscopical examination would be evident from the following considerations. It had been well established that when certain microscopical plants of the nature of bacteria pervaded a water, to drink such water often gave rise to remittent fever, splenic fever, and pig typhoid. Chemistry was unable to discover these microscopic plants; but a competent medical practitioner acquainted with the properties and habits of those minute organisms could detect at least many of them and others of different kinds. In June 1852 both the late Dr. E. Lankester and Dr. Redfern, the present professor of anatomy and physiology in Queen's College, Belfast, found from thirty-two to thirty-eight species of microscopic organisms, some plants, some animals, and some diatomaceæ, besides large numbers of each species in half a gallon of water, drawn direct from the supply pipes of the Lambeth Company (taking its supply at Thames Ditton), before entering any house cistern. In 1857 Dr. Hassall, in a report to the then President of the General Board of Health, stated that any water drawn direct from the mains of each of the waterworks under the provisions of the Metropolis Water Act 1850, still contained considerable numbers of living vegetable and animal productions belonging to different orders, genera and species, but especially to the order or tribes annelidæ, entomostraceæ,

infusoriae, confervae, desmideae, diatomaceae, and fungi. Dr. Mr. Homer-Hassall stated that the examination was made in winter, and that other examinations should be made in spring, summer and autumn. No such further examinations, however, had been made by order of the Government. That, he thought, was a great dereliction of duty on the part of some Department. Winter, it was suggested, was not the time to find the plants so well as summer and autumn, yet no other authorised examination had been made. The waters of the various companies were subject only to chemical examination. In the last Report of the Government Water Examiner under the Metropolis Water Act 1871, a chemical analysis was given by Dr. Frankland, another by Messrs. Wanklyn and Cooper, and another by Drs. Bernays and Tidy. In that Report, there was no mention of microscopical examination. If microscopists were employed to examine the water month by month they would find out the species that were more frequent at one season than another, and ascertain in what water they abounded. It was well known by those who had paid attention to the subject, that many classes of those plants and animals indicated unwholesome water, and that these were mostly to be found in warm weather. It was true that Dr. Frankland, with his analyses, reported that the Grand Junction Company's water contained moving organisms, but no particulars were given; while in the reports of Messrs. Wanklyn and Cooper and of Drs. Bernays and Tidy the presence of any organisms was ignored. That reminded him that only the other day a shareholder who wrote in *The Times* newspaper stated that the Company was satisfied with the Report of its chemists, because they did not mention any living organisms; but it was not because there were none, but because no microscopists had been employed to detect them. Surely if it was worth while to have the companies' waters chemically analysed once per month by five professors of chemistry, it should be made a point to have at least one examination of the waters in a month by a competent biologist and microscopist. In obtaining samples of water from distributing pipes for determination of the organic contents, the water to be examined should be drawn not only direct from a main but near to the "dead end," as it was technically called, of a rider pipe, or to the dead end of a service main placed in a side street, for the organisms existed in much larger quantities near the dead ends of mains than in circulating mains. The creatures were so intelligent that where they found the water quiet they went to live and breed. Chemists sometimes asserted that water had not been

Mr. Homer- properly filtered. Filtration in some respects really injured the water in summer, because during the process there was collected on the top of the sand a further quantity of organic matter that became decomposed, and furnished pabulum for the insects. The Author had stated that reservoir- or lake-water contained but a small quantity of organic matter, but he did not agree with that statement. It would be found by the Registrar General's Returns that wherever lake-water was supplied to town there was an excessive mortality. But, putting that aside as there were many other things to cause mortality besides impure water, yet such things as the excreta of animals, liquid and solid leaves and the like were unavoidably washed into the water. Water contamination in lakes also arose from the formation of mud on their unlined sides and bottoms. It was impossible to prevent the formation of this mud, which was congenial to the production and growth of animal and vegetable life. The water from Loch Katrine and the water supplied to Manchester were full of dead organic matter and living organisms, especially in summer. The Author had further stated that very slight contamination took place in water when exposed in the open country; but he could not agree with that statement. He remembered having a large reservoir lined with cement on the South Downs, for the supply of Brighton. The water was perfectly pure when pumped from the wells and into the open clean reservoir, but in a few hours in the summer, there were masses of *confervæ* growing on the top of the water, and soon after a number of insects of different orders bred and flourished in it. It was a serious expense even to clear out the reservoirs and keep them clean in the summer. The evil could not be prevented except by roofing them over. Carbonic acid was given off from bicarbonate of lime, which formed the pabulum that the species of the *confervæ* required, and the consequence was the water polluted though the open reservoirs were in the country. He had seen open reservoirs in a hot day when clouds of insects had been blown by the atmosphere into and upon the water in the open country. It was an entire mistake to suppose that water could be kept pure in an open lake or reservoir because it happened to be in the open country. The temperature of the Thames in a hot summer was as high as 72°, and in the winter it was as low as 35°. Water, when it was warm, lost some of its oxygen, and plants and animals bred in it to a much larger extent than when it was cold. The loss of heat in winter, bringing the water down to within 3° of freezing point, rendered it liable to freeze readily in the consumers' pipes,

this burst them. There was another point on which he disagreed with the Author, that water to be purified must undergo a process of distillation by the heat of the sun. Water that fell on uplands composed of porous strata, such as sandstone, chalk, &c., was absorbed and percolated downwards often to great depths through the pores of the strata. A quantity of water was held in the pores by capillary attraction, and diffused through its mass. The varying density of the air brought the water thus held by capillary attraction in contact with changed oxygen, and by that process long-continued deprived the water of any organic matter it might have possessed. Supposing a depth of 18 inches of rain to go down through the surface in the course of a year, as the chalk strata were on an average more than 600 feet in thickness, and one-third of the bulk consisted of pores, it followed that it would require a depth of at least 200 feet of rain, or the produce of one hundred and thirty years, to saturate the pores.

Professor TYNDALL observed that Mr. Homersham had had very valuable experience in regard to the subject under consideration. He had gone with Mr. Homersham to Canterbury, and seen the chalk-water there, and the mode of softening the water according to Clark's process. He did not know that he had ever seen a more beautiful experiment upon a large scale. He had also seen the same thing at the Chiltern Hills and at Caterham, where the works were under the supervision of Mr. Homersham. There was one point, however, in which he was inclined to differ from him, and to agree with previous speakers. He was rather doubtful as to the ability of a microscopist, even though he were a medical practitioner, to detect in water the germs that were chiefly damaging to man. He would take the case referred to by Dr. Thudichum, and a more lucid medical investigation he had never known. There was an outbreak of typhoid fever at Redhill and Reigate, where more than three hundred persons were attacked. Dr. Thorne Thorne went there, got hold of the tag-ends of his facts, fitted them together, traced them backwards, and finally came with the utmost certainty to a single individual who had been employed in sinking the well at Caterham, and whose excreta had infected the whole neighbourhood. Imagine the diffusion of the infective matter through all those long pipes, and a medical practitioner trying with his microscope to find out the little infective particles. In his opinion it would be a hopeless task. In the case of that most virulent disease, splenic fever, which had been worked at so successfully by Pasteur, the germ was easily seen. It was a large bacterium. But there were

Professor Tyndall. bacteria that were not easily seen. He had, for instance, cascade near a little house on the Alps, 7,000 feet above the sea, and although it was charged with water coming from the snow-fields of the Alps, if he took a speck of that clear water and infected an organic infusion with it, in forty-eight hours the infusion would become putrid and swarming with organisms. He once chose a piece of the clearest ice he could find, placed it under the receiver of an air-pump with perfectly moteless water around it, and allowed it by fusion to wash its own surface. From the heart of that ice, clear as crystal, he took a quart of water, and gave it to Dr. Burdon Sanderson, who found it contained germs of bacteria just as effective in producing putrefaction as ordinary water. He should not, therefore, be inclined to accept the notion that germs were so easily detected by the microscope. He agreed with Dr. Thudichum, that chemical analysis would afford but little information as to the deadliest things that might be in water, and that the microscopist could tell very little about them; but that the best way was to draw water supply from sources where contamination could not come into play, and in that respect he desired to say that Mr. Homersham stood conspicuously among engineers.

Mr. Hogg. Mr. JABEZ HOGG remarked that, as a microscopist of some experience he agreed in part with what had fallen from Professor Tyndall as to what the microscope could do, and what it could not do. He admitted that the microscope had never disclosed the kind of bacterium that would produce a specific form of disease, but he could not agree with him that the microscope could not detect the presence of bacteria. It could not perfectly detect the exact formation of the creature moving under the field of the microscope; but microscopists could say something that was there a little beyond their ken, and medical men and physiologists could carry it a little further, and take some of the most virulent and most infectious germs, and produce a physiological action in the blood of an animal, and in that way confirm the suspicion that there was something wrong with the water. As to the particular method to be pursued and carried out in researches of the kind, he was pleased to find the Local Government Board bringing its authority to the elucidation of this point. An independent commission was taking steps that would tend to set the vexed question of contagion at rest. A very competent gentleman was proceeding to make a series of experiments to ascertain what amount of significance could be attached to current methods of chemical analysis of potable waters. He took samples of water,

only polluted them with stools of typhoid or enteric fever Mr. Hogg. patients, and compelled animals to partake of them. The results already obtained were startling, and sufficient to confound some who were strong in their belief of chemical analyses, and of those who persisted in jumbling together the evidence of organic impurity and the evidence of unwholesomeness. In the first part of the Paper, various ways had been mentioned in which water became contaminated. He desired to point out the great necessity for using precise terms in reference to such matters. Dr. Thudicum had spoken of spring-water. Spring-water was water that many persons would not like to drink. He supposed Dr. Thudicum meant water drawn from subterranean sources at great depths by an Artesian well. If this were so, he might be permitted to refer to the inquiry into the Molesey irrigation scheme. It would be remembered that the Molesey people wanted to irrigate certain lands with sewage, and it was discovered that the Lambeth Company was drawing 2,000,000 gallons of its water daily from a gravel-bed subsoil source at Molesey. This underground water was discovered when putting down conduits. The pipes were found to be passing through an immense body of water, and the engineer thought he could not do better than pump it up and use it, and call it spring-water. This was done for a considerable period, and it was supposed the Company were pumping deep well-water. The water was submitted to chemical analysis, and pronounced "perfectly pure and wholesome;" on closer investigation, it was found that the water was in a very bad and unwholesome state. In the course of the judicial inquiry Mr. Michael said: "This is neither more nor less than diluted sewage of a most dangerous nature?" The engineer replied, "Oh no, it is not, for it has been filtered and submitted to our chemist, who pronounces it pure wholesome water." Among the chemists who pronounced it to be pure and wholesome was, he thought, Dr. Tidy. It had apparently not entered into the calculation of any one, that in drawing subsoil-water from an area of some extent (in this instance a radius of more than $1\frac{1}{2}$ mile) the whole incidence of that area must be taken into account. Now, it so happened that at West Molesey it included seven hundred and seventy cess-pools, all of which were being pumped dry, and mixed in with the Company's water. A Government investigation ended in putting a stop to that objectionable mode of drawing a supply of "spring-water."

Dr. Tidy said it was a mistake to suppose he had certified to the Dr. Tidy. wholesomeness of this water; on the contrary, he had condemned it.

Mr. Hogg. Mr. JABEZ HOGG said he was glad to hear the statement of Tidy, but he knew that the chemists of the company had expressed an opinion that the water was perfectly pure and wholesome. He could not for a moment doubt Dr. Tidy's word, but there were one or two points in connection with other of his statements which he desired to notice. He had contended that if the Thames river water had a run of a certain number of miles it would rapidly oxidise all the sewage mixed with it. "His results," he said, "were in accordance with those of all the chemists who had examined and reported on the subject; and he also believed that the Thames in its flow of 130 miles as a definite stream would not acquire any increased proportion of organic matter." If Dr. Tidy had examined the water at Lechlade as well as 130 miles lower down, but of which he afforded no evidence, his results would have been apt to mislead. From the first part of his statement it would appear that the Thames was as pure at Hampton as at Lechlade, the water not having acquired any increased proportion of organic matter; but the results he had published did not show the condition of the water in the river 130 miles below Lechlade; they merely showed its condition after it had passed through the company's filters. Looking, however, solely to the condition of the water after it had been filtered, and applying Dr. Tidy's theories concerning the rapid destruction of organic matter, which at Lechlade proceeded from a scantily populated district, might be taken to be comparatively free from sewage, all organic matter would, according to his theory, have been destroyed before it reached Hampton; whereas that which replaced it, coming from towns situated between Lechlade and Hampton, would contain sewage contamination from numerous populous towns. The organic matter, therefore, even if it were large in amount, would be worse in quality, and the water of course inferior. In fact all the towns situated on the banks of the Thames were constantly pouring in large quantities of sewage, and it could be no run of more than 100 yards, to say nothing of 130 miles, where pollution was not going on day and night. Who could undertake to say when and where some typhoid or malarial patient would not be sending excreta into the Thames in a course of 130 miles? Turn to the report of a chemist who differed from Dr. Tidy—the official water-analyst of the Government, Dr. Frankland, whose experience in such matters was beyond all question. He had spoken in his report of the impure condition of London water, which he said was due to the want of efficient filtration; but Dr. Frankland's opinions were strongly adverse to the use of Thames water for drinking.

pen, on the ground that it would not be safe so long as sewage Mr. Hogg. had access to it. Actual danger might arise in the production of diseases believed to be propagated by organisms possessing a remarkable degree of vitality; and when seasons conducive to an epidemic outbreak supervened, it was imperatively necessary that water-pipes should not become vehicles for the spread of disease. The important point of divergence between Dr. Frankland and Dr. Tidy, who were both working from the same data, consisted, not in any marked difference as to facts, but in a difference of opinion as to the import of those facts. That was a point which should be clearly understood and weighed when misleading chemical reports were issued to the public. Dr. Tidy of course fell back upon the Registrar General's Reports, as showing that there was no increase of deaths in London: but he omitted altogether to take into consideration how much London had advanced in its sanitation during the last twenty years; how much care had been bestowed by Officers of Health, not only in benefiting the poorer portions of London, by turning out the poor people and letting in light and air, but also in improving the health of London generally. There was scarcely a person, whatever might be his position in life, who had not benefited by what had been effected in that respect. He agreed with the Author in his general conclusions, and was ready to admit that he had done a great service in opening out so important a question.

Mr. W. ATKINSON said it appeared to him that the whole force Mr. Atkins of the Paper depended upon the question whether zymotic diseases were the result of the growth of living germs in the human frame. The Author admitted that water, if it contained dead organic matter, in passing down a stream was purified, and he assumed, what Mr. Atkinson believed had never been proved, that zymotic diseases were dependent upon living organisms of such great vitality that they were almost indestructible. He knew that Professor Tyndall and Mr. Hogg were high authorities on the subject, but he did not know that there was anything to contradict the statement of Dr. Tidy that there was as yet no absolute evidence of living germs propagating those specific diseases. The question of chemical analysis, he thought, had been pretty well cleared up. The Author had stated that although chemical analyses did demonstrate the presence of organic impurity, yet it did not enable a decision to be made as to whether it rendered the water unwholesome. That had been fully borne out in a little work by Mr. W. Noel Hartley, Demonstrator of Chemistry at King's College, who stated at page 23: "Even in very un-

Mr. Atkinson. wholesome waters the amounts of organic matter are exceedingly small. The chemist can tell how much carbon and how much nitrogen this organic matter consists of, but he is powerless to say, by applying any distinctive test, that he is acquainted with the nature of the organic matter, and that it is such as will act as fever poison or as cholera poison."

Mr. Ekin. Mr. CHARLES EKin said that, at a recent discussion at the Chemical Society on that question, Professor Huxley pronounced an emphatic opinion that water might be as pure as possible from a chemist's point of view, and yet be most deadly; but he did not undertake to say as a physiologist that it was possible to detect the organisms or organic matter contained in it. Mr. Ekin quite agreed with the Author and Dr. Thudichum as to the little value to be attached to the determination of organic matter in water, because he had, over and over again, examined water that had undoubtedly given rise to typhoid fever, and found that it contained a very small amount of organic matter, and he had gone into districts where there could be no sort of contamination, and examined the springs, rivers, and brooks, in which he had frequently found large amounts of organic matter, that by no test could be distinguished from the organic matter in sewage. It was well to keep in view the fact that contamination was simply a question of degree. Dr. Thudichum would always go to springs, but he hardly realised the difficulty of getting pure spring-water and keeping it pure. Towns that were using springs for their supply were getting more and more alive to the necessity of buying land around the springs, to prevent the water from being contaminated by highly-manured fields or market gardens. Nearly all the water used for drinking purposes in England must be more or less contaminated, because it was collected on surfaces highly cultivated and thickly populated. With regard to the question of previous sewage contamination, the Author overstated the case when he said it was impossible to tell whether the nitric acid and ammonia present in any water had been derived from rain-water or from the soil through which the water had percolated. As a matter of fact it was easy to distinguish between the two, as the amount in rain-water did not exceed a certain very small percentage, and deducting this, the quantity derived from the soil was arrived at. Although the term "previous sewage contamination" was in some respects a misleading one, still there could be no doubt that the determination of the items included under this head afforded useful data in judging of the wholesomeness of drinking water.

Mr. FOLKARD in reply said, on the two questions of the insufficiency of the present methods of chemical analysis, and the danger of using water which had been once polluted, he proposed making a few remarks. With regard to water analysis, the statement which provoked so much controversy, that chemists were powerless to discriminate between wholesome and unwholesome water, he would quote from Memorandum No. 3, on Drinking Water, issued by the Rivers Pollution Commission:—"The existence of an infectious property in water cannot be proved by chemical analysis." If chemists could not tell whether a given water was possessed of infectious power or not, he thought it was fair to say they could not tell whether it was wholesome or not, and therefore the statement in the Paper was corroborated by the opinion of Dr. Frankland. Again, he agreed with the opinion frequently expressed by engineers, that a chemist should be able to give a decisive report on a sample from the results of his analysis alone, irrespective of the origin of the sample. If a mineral was submitted for analysis, the chemist or assayer was indifferent as to where it came from or at what depth it was obtained. He could report with certainty on the percentage of iron or copper, as the case might be, and if the processes of water analysis were reliable like those of inorganic analysis, water analysts could report with equal certainty whether a given sample was wholesome or not from the results obtained, irrespective of its locality or source. Whether water analysts were willing to give a report when thus left in the dark he left to engineers to decide. He knew that in at least one case this was not so, and that gentleman had had considerable experience, as he had it on good authority that several thousands of samples had passed through his hands. This seemed to show that neither Dr. Frankland, nor any other experienced water analysts, placed absolute reliance on the results of chemical analysis to show whether a water was wholesome or not, and consequently they agreed so far with the opinion expressed in the Paper. It was contended that the great question was, "What is the condition of the water now? not what was its condition fifty years ago, or 50 miles up-stream." This was perfectly true, but unfortunately it was a question which no water analyst could answer. The various processes of water analysis had one and all been shown on chemical grounds to be worthless, and he had endeavoured to prove that they were worthless (as far as the power of indicating wholesomeness was concerned) by reasoning which required no technical knowledge to

. Folkard. follow it, but simply the exercise of common sense. Eminent water analysts had brought forward apparently conclusive evidence of the worthlessness of all processes of water analysis except their own, and he was convinced that each one of those chemists was right, and begged to refer to their communications on the subject for proofs of worthlessness on chemical grounds. Further, he believed that the cause of the want of confidence of engineers in the results of water analysis was due to the unavoidable employment of defective processes, in the absence of better and reliable ones. That this want of confidence existed he knew, because many of his friends were engineers connected with water-supply, and he ventured to think many could from their own experience corroborate the views at which he had arrived on theoretical grounds. If this were so, the sooner analysts owned it the better, instead of attempting to throw dust in people's eyes, and to bolster up defective methods by saying they had employed them so many thousand times. Consider the method of ascertaining the present condition of a sample of water by the permanganate of potash process. A measured quantity of water was put in a glass standing on a sheet of white paper, and it was noted how many drops of permanganate of potash were required to communicate a permanent pink colour to the water. To give it its due, the process certainly had the advantage of simplicity, and after performing the experiment some three hundred or four hundred times it might be a matter of question whether further repetition would greatly add to the operator's skill in water analysis. The sooner the water became pink, the less the amount of foreign matters present; but as to the nature of these substances every one was in the dark, and when it was inquired if Letheby, who invented the process, or Dr. Tidy, who used it, had established any definite relation between wholesomeness and permanganate, there was no answer. An intelligent lad could master the details of the process in half an hour, while, as before mentioned, the value of the result was admitted by nine-tenths of analysts of the present day to be *nil*. He thanked Mr. Ekin for supplying an omission in the Paper at page 60, line 15. After the words "by the rain in falling" it should have been mentioned that the amount of nitrogen existing as ammonia and nitric acid in rain being very small, anything in excess of the normal amount might, as stated by Mr. Ekin, be fairly put down to animal or vegetable contamination. He could not agree with Mr. Hon. Mr. Asham's remarks on hard water. The quantities were so small that it could make but little difference for dietetic purposes whether

there were 5 grains or 40 grains of chalk per gallon. Besides Mr. Folke many medical men were of opinion that lime in drinking-water was essential to the health at all events of children, and therefore he could not but think it unfortunate that Dr. Frankland should return such harmless inorganic substances as chalk under the heading of impurities. Although perfectly correct from the chemist's point of view it was liable to mislead the non-scientific portion of the community. The second question was as to the purification of rivers by natural means. Of course a great deal took place in this way, otherwise (as had been remarked) no one would be alive. Vegetation had a most beneficial influence, although he ventured to think that in nine months of the year in this dull climate the effects could not be very energetic. It must also be remembered that vegetation was supported by inorganic materials, and that the organic matters contained in sewage must decay and be resolved into the salts of ammonia, carbonic and nitric acids, before they became available for the support of plant-life. All this of course took time. The statement made by Dr. Tidy, however, was so extraordinary that it would well repay a little attention. It was to the effect that 10-miles flow was enough for purification (whatever that might mean). The velocity of the river might be assumed to be $2\frac{1}{2}$ miles per hour, whence it followed, according to this theory, that in four hours purification had taken place. If Dr. Tidy meant that river beds showed no signs of sewage 10 miles below the outfall, the statement was probably true, but even that would depend on the ratio of the volume of sewage to the total flow of the river. But the assertion that sewage was decomposed in four or six hours was rather startling. Even admitting this would be the case in the height of summer during sunshine, and when vegetation was most active (and very few if any chemical actions, especially in dilute solutions, were complete in such a short time), what should be said about the winter months when sunshine was almost an event, and the temperature of the water was near the freezing point, the processes of vegetation and fermentation being nearly suspended? To say nothing of the fifteen hours' darkness of the winter night during which no purification by the aid of vegetation went on (light being essential), and in which time the sewage would flow with the stream 30, 40, or 50 miles. He submitted that the 10-mile estimate was far wilder and more fanciful than any assertions in the Paper, in addition to which it was entirely at variance with facts. The Rivers Pollution Commission Report contained two analyses of the water of the Thames, viz., at Reading and at Shiplake paper-mill,

Dr. Folkard. and the result showed that after a flow of 4 miles the organic carbon in the water was only reduced by about 6 per cent.; and assuming that the diminution went on in the same ratio, a flow of at least 64 miles would be required in summer to effect decomposition, the date of the experiment being May 31st, 1873. As a matter of fact, however, such processes were almost invariably more and more sluggish towards the close, in addition to which there was absolutely no evidence to show that the morbid material (he was half afraid to call them germs) were acted upon in the slightest degree. The above experiments should be pretty conclusive to Dr. Tidy, because the organic carbon was the constituent which agreed so very closely with some of his numerous determinations, and the correspondence of which with his own method put forward as almost conclusive evidence of the reliability of both processes. After the severe remarks about germs, it was a comfort to him to reflect that he was not the only person who believed in their existence. To his mind the evidence was as conclusive as of the presence of calcium, sodium, iron, &c., in the sun's atmosphere, and in both cases amounted to far more than a probability. To some minds however, the fact of their having been seen was fatal to the possibility of their existence, but it should at least be recognised that several eminent men believed in them. The town referred to in the Paper in which an outbreak of enteric fever occurred about three years ago was Caterham. Dr. Thorne Thorne investigated the matter, and made a full report on the subject. The evidence was direct and conclusive that water contaminated with the dejecta of a workman suffering from enteric fever was the cause. An epidemic of typhoid occurred in the village of Lausen, near Basle, Switzerland. The case was investigated by Dr. Hägler, and experiments were made similar to those mentioned by Mr. Bald Latham, viz., by throwing about a ton of salt into the water of a stream opposite the cottage in which the first attack of typhoid occurred. In two or three hours' time the water at the next village became perceptibly salt, and this was corroborated by the precipitation test. Some 20 or 30 cwt. of flour were then thrown into the stream to ascertain if the water was subjected to any filtering process. None of the flour (although well mixed up with the water) arrived at Lausen, conclusively proving that filtration, which was effected in stopping such comparatively coarse particles as those of flour, allowed the specific poison of typhoid to pass in sufficient quantity to strike down 17 per cent. of the population with the disease. A more detailed description had been given in the Proceedings

of the Chemical Society, February 17th, 1876. It had been urged Mr. Folken that the outbreak of fever at Caterham would not have occurred if the contaminated water had flowed in contact with the air as a river or brook instead of in closed pipes. Of course this was possible, but it was a mere assumption, unsupported by evidence; fortunately for sanitarians and the public the Lausen case just described set the matter at rest, a mountain stream then being the vehicle of the typhoid poison. After this it would hardly be advisable to rely on germs being destroyed in flowing water. With reference to Mr. Baldwin Latham's remarks on the death-rate of London having slightly decreased, while the impurities in the river-water had increased in quantity, it must be remembered that the sewerage system and the sanitary condition of the houses had undergone vast improvements, and therefore to his mind it was exceedingly disappointing that a far greater diminution in the death-rate had not been observed. The late Dr. Letheby pointed out that the real death-rate of London was probably very different from that shown by the Registrar General, the population being continually recruited by young people from the country; also the sick were, in as many cases as possible, removed into the country, and of course many thus died away from home. These causes probably made a difference of at least 5 per 1,000, if not considerably more, and therefore there was no reason to boast of the corrected death-rate of the best sewered city in the world. The statistics of the cholera epidemic of 1854 conclusively showed the ill effects of a foul water-supply, the relative mortalities being as 13 to 4. The fact of the death-rate of the districts of the metropolis, supplied with river-water, being the same as that of the Kent Company's district, was doubtless due to the greater number of recruits from the country who settled in the former area. If London were increasing eastward as rapidly as westward the cases would be parallel, and Dr. Tidy's conclusions would hold good, but in view of this great disturbing element (the influx of young people from the country into the western or river-water districts), such comparisons were almost valueless, merely showing that even with such great advantages the river-water area death-rate was not lower than that of the well-water area. He could not admit that the question of storm overflows was irrelevant. It was immaterial to the inhabitants of the lower towns on a river whether these overflows were theoretically necessary or not. The question to them was "Did the sewage flow direct to the river in times of heavy rain?" In connection with this subject it should not be forgotten that the sewage thus discharged direct was in its

Folkard. foulest state, the great rush of water flushing the sewers and bringing with it accumulations of filth which had been collecting and festering, possibly for weeks. It would be a question of expense, viz., the construction of sewers in the upper towns large enough to carry off storm-water without the necessity of using storm overflows *versus* the obtaining of the water-supply of the lower towns from other sources than the river. There could be no doubt that the upper towns would feel it a great hardship to be obliged to spend two or three times as much on their sewerage system from this cause, and in view of the partial and imperfect nature of the remedy this extra outlay would not be justified. He must also dissent from Mr. Latham's inference that low death-rates were the accompaniments of offensive states of rivers. It was probably a mere coincidence and could hardly be taken as proof of the harmlessness of such an abnormal state of things. The fact of malaria usually travelling up stream was irrelevant. It was prevalent in almost uninhabited countries, and was due to conditions of heat and drought simultaneously present in the upper and lower parts of a river. With reference to the effect of water containing the evacuations of cholera patients on the inhabitants of Birmingham, he did not think it was fair to expect an explanation of every case. That injurious effects had followed the use of such water (putting sentiment aside altogether) had been proved in England and on the Continent. It seemed to him that when an admittedly polluted stream was to be used as a source of water-supply, the onus of proof of its innocuousness rested on those who proposed it. It was not enough to show that no ill effects had been observed in particular instances. On the contrary he thought two or three undoubted cases, of the transmission of disease by such waters, should be enough to condemn them as a class, and prevent wherever possible their use for domestic purposes. Besides, the mere idea was so loathsome that one almost wondered that an attempt should be made to defend it. If "drinking in a circle" were unobjectionable, then why have such refinements as sanitary inspectors, inspectors of nuisances, and food analysts? It certainly seemed inconsistent. The question had been put to him "admitting the presence of germs, was there any evidence to show that they were not amenable to the same laws as organic matter generally?" Here the necessity of extreme precision would be seen. The term organic matter was indefinite. If living organic matter were meant the answer would be self-evident, because germs were living organic matter, and therefore must be amenable to the laws governing such matter. If on the

other hand his interrogator meant dead organic matter, he replied Mr. Folkard, that germs were no more amenable to the laws of dead organic matter than a living man was. Again, every biologist was aware that the lower the organism the more persistent was its vitality, as a rule, and therefore a living germ was at the very least quite as capable of resisting oxidation during a 10 or 100, or 1,000 miles swim down a river (water being its appropriate medium) as was a hen's egg for an equal time or during transport through an equal distance in its appropriate medium, the atmosphere; and he thought few people would doubt the capacity of a hen's egg to germinate after such an interval and such treatment. Under the circumstances he could leave the members of the Institution to decide which of two chemists was the more likely to gain respect, the one who, after ten years' experience in water analysis, had come to the conclusion that the present methods were unreliable, and was willing to own it; or on the other hand, the one who tried to throw a halo of importance round a process admitted by nine-tenths of the analysts of the present day to be worthless, by stating that he had analysed nearly four thousand samples by it. It would be equally logical to say that hanging for sheep-stealing was a good law because it had (unfortunately) been carried out hundreds of times in this country. In conclusion he must thank the members for the kind way in which they had listened to the Paper and to his remarks, and if it should be the means of directing still further attention to this important subject he should be extremely gratified.

Correspondence.

Mr. H. PERCY BOULNOIS said that the Water Works of the City of Exeter, of which he had charge, were the property of the Corporation. The daily supply, amounting to 1,280,000 gallons, was pumped from the river Exe, the intake being situated about 4 miles above Exeter and 12 miles below the town of Tiverton, the sewage of some ten thousand persons at this place being daily passed direct into the river in a crude state.

To ascertain how far this sewage contamination chemically affected the water, he took samples from different points in the river in August 1880, and submitted them to Mr. F. P. Perkins, the public analyst of the City of Exeter, who examined them by the permanganate process and a modification of Professor Ditt-

Boulnois. mar's carbon process. The following Table embodied these tests :—

SPECIMENS of WATER TAKEN by Mr. BOULNOIS from the River Dart
AUGUST 16th, 1880, and SUBMITTED to Mr. PERKINS for ANALYSIS

Number of Specimen.	Where Obtained.	Distance below Tiverton.	Amount of O ₂ 100,
			Oxygen consumed.
1	Above Tiverton . . .	1 mile above . .	·0718 × 100
2	Below Tiverton . . .	100 yards below	·0873 × 100
3	Ditto	2 miles „	·0929 × 100
4	Bickleigh Bridge . . .	3 „ „	·0788 × 100
5	{ In a stream joining the Exe called the Dart }	3½ „ „	·2070 × 100
6	{ Below Bickleigh mill stream }	3½ „ „	·0859 × 100
7	Bourne Farm	5 „ „	·080 × 100
8	{ Thorntown above the weir }	8 „ „	·0831 × 100
9	At intake	12 „ „	·0715 × 100

It would be noted, on reference to this Table, that the intake was chemically nearly similar to that above Tiverton, and that this result was obtained gradually by the journey. The Dart stream, however, seemed to pollute the water there being a marked difference between samples 4 and 5, which was accounted for by the fact that the Dart rose on the Dartmoor, although it could receive absolutely no sewage contamination, and was brown with peat, and this gave a bad analysis.

So far as Exeter was concerned, it was contended that the water at the intake was not unhealthily affected by the sewerage emanation of Tiverton, and this result might be attributed to the following causes :—(1) The excessive dilution of the water by a large bulk of pure water. (2) The oxidation which the water underwent on its 12 miles journey from Tiverton, to Exeter, it did so over two weirs and rushing over many a shallow bed. (3) The action upon the water by aquatic plants and of the soil of the river banks and bed. (4) The evaporation from the surface of the water, and consequent chemical changes thus altering its character. (5) Other causes possibly at work which made up the ever acting of Nature's great laboratory.

The Author questioned the reliability of chemical analysis to detect "previous sewage contamination," but he did not

have given credit to the fact that, in a properly conducted analysis, Mr. Boulton the chemist relied upon one indication only, but that all the bearings of the analysis and history of the water were considered. If the analysts' evidence was to be doubted, much difficulty would be experienced by sanitary authorities in closing polluted wells or other impure sources of water supply; but hitherto reliance had always been placed upon such evidence, and he thought no sufficient proof had been adduced in the Paper to shake public confidence. The question was one of grave importance, the health of a community being no doubt greatly affected by the character of its water-supply; no hasty conclusion should therefore be arrived at in favour of deep well-water. It might be that the terrible "diseases of the stomach and intestines" mentioned in the Paper were due to contaminations in shallow well-waters, or to the mineral substances found in most deep well-waters, and not from that source which Nature pointed out as the most convenient and proper from which to derive the water-supply.

Mr. EDWIN CHADWICK, C.B., observed that there were particles Mr. Chadwick from small-pox and other eruptive diseases, which were known to be distributed in hospitals within measurable distances. But these were imagined, but not proved, to be germs of specific diseases which spread to immeasurable distances, and which it was averred must be productive of the same diseases. These germs were alleged to be the cause of enteric fever, and when conveyed by water-carriage must generate it. A disease did arise sometimes, with varying type, from the emanations from stagnant drains or sewers. But he never heard of any arising in such conditions along lines of sewer in accordance with the germ theory. In an address given at Croydon to the members of the International Medical Congress by Dr. Alfred Carpenter, adducing experiences in answer to the violent objections that had been made by the advocates of chemical disinfectants, and other processes against sewage farms, on the grounds that they must receive and must spread the germs of infectious disease. Dr. Carpenter stated the result of his experience, to which he would direct particular attention: it was as follows:—

"The non-infectious character of the excretions of those suffering from epidemic and infectious diseases when distributed upon a sewage-farm is proved by the fact that there have been occasional outbreaks of infectious diseases in Croydon during the past ten years, including two epidemics of small-pox, several outbreaks of scarlet fever, occasional cases of diphtheria, and three periods of typhoid prevalence—two of which were distinctly connected with contamination of water-supply in its distribution, and a third was distributed by means of milk. In the years 1875–76 the excreta of at least a thousand cases of enteric fever were

Chadwick. utilised on the farm. In the majority of the cases the excreta were certainly not disinfected, and had they been capable of setting up the disease, some of the sixty-five persons at that time in the employ of the Local Board must have suffered from the infection. Cases which did arise were not on the farm, or even in the majority of cases, near to it; they were on the hills, beyond the range even of subsoil water. The changes in sewage are not in any way similar to those which have been known to take place in poudrette and other particular forms of dried ordure. There is no doubt in my mind of the destruction upon sewage farms of the germs of mischief, which, when unaltered, may be capable of setting up zymotic disease. They are not preserved as they may be in dried ordure, or in other products in which so-called disinfectants have been used, which have simply preserved the germs from decay; but they are chemically and physically altered so that mischief cannot arise. This result has been also found to apply to the excreta of animals suffering from epizotic disease. During the past few years there have been several outbreaks of infectious pleuropneumonia in the Croydon district, the infection being brought from the Metropolitan Meat Markets. The cowsheds in which the disease has arisen have drained into the Croydon sewers, and blood and excreta from the slaughtered animals have been washed down those sewers. The sewers have carried the morbid matter from the sheds to the farm; but there has been no corresponding disease among the cattle upon the farm."

To this he might add that similar demonstrations were presented by all well worked sewage-farms. Moreover, insects generated and distributed in solid manures, and in stagnant semi-liquefied manures, were drowned by liquid manures in active circulation. It must follow that from continued exposure to such germs as those assumed that the health of those working on the sewage farms must be lower than the average, whereas it has been shown in a report to the Royal Agricultural Society that the health of the people working and living on the sewage farms was remarkably higher than the average.

De Rance. Mr. C. E. DE RANCE remarked that the Author, by grouping a series of well-known facts in a definite connection, had done useful work, in establishing the unassailable result, that the practical freedom of drinking water from organic impurity must be absolute to prevent the spread of zymotic disease. How this desirable condition was to be obtained was a difficult problem. Gravitation supplies, derived even from the mountain slopes of Wales and the English Lake District, traversed only by mountain sheep, occasional tourists, shepherds and their dogs, were liable to receive the germs of entozoa, especially from the latter; while water supplies abstracted from rivers, even when all town sewerage was intercepted, received streams flowing past polluted farm yards, and the soakage from the offensive ditches with choked outlets, which so often surrounded them. In a gravitation supply absolute freedom must of necessity be impossible, but much could be

affected, by making the separation of sewerage and storm-water compulsory, not only in the drainage from cities and towns, but in the effluent water from country estates.

In water obtained from underground sources, whether from deep-seated springs, or wells, the chances of poisonous germs being left was very small, after the passage of the water through several hundred feet of porous rocks, provided that the water had passed through the texture of the rock, but in many cases, the water had simply travelled, both vertically and horizontally through open fissures formed by joints and faults, and this was probably the condition of many wells giving an exceptionally large daily yield of water, which had not been naturally filtered. In some other cases, deep bore holes had been sunk entirely in porous rock, in which every care was taken to exclude, and tube out, surface waters, but the water yielded was found to be polluted, percolation having taken place through cracks and fissures, connecting the surface with the saturated portion of the rock beneath. Of necessity wells reaching porous formations after passing through a zone of impermeable material were not open to this objection, and the chances of pollution were exceedingly small in the water yielded by them and by deep-seated springs. To increase the yield of these springs appeared to be a matter of the highest importance, for should the construction of "dumb wells" become general, and the drainage of impermeable lands be artificially carried to porous strata beneath, whenever practicable, the supply of pure drinking-water would not only be increased, but the absorption of excessive rainfalls would diminish the intensity of floods, and improve the dry-weather volume of the streams.

Mr. H. U. McKie knew one town in Wales which took its water-supply from a river, when about 1 mile of extra piping would have given good spring-water. Villagers near the river from which the water was taken would not use it, yet chemists pronounced it pure. He had recently had occasion to examine some works by a river side, and saw what he thought to be two sticks floating down the rippled surface of the stream; they appeared to be attached together by a string, and made curious bobbing motions, similar to a float on a fishing-rod when there was a nibble at the bait; on closer examination he found it was a large salmon so covered with a fungoid growth as to be both pitiable and revolting, and he was told that the river was full of salmon thus affected. Now, as this disease also attacked trout, eels, and other fish, in the river, he thought it right to ask if water so contaminated could be a safe source of potable water-supply for a town? He knew of two

Mr McKie. towns on this river which derived their water-supply from it, and there might be others.

Mr. H. ROBINSON could not agree with the Author in his sweeping condemnation of the use of river-water unless taken near the source. However desirable it might be to obtain water free from the risk of contamination (and every engineer aimed at securing such a supply) in practice it would be impossible to meet the wants of the community, if the rule laid down were acted on. The enforcement of this rule would necessitate the abandonment of numerous sources of supply which failed to comply with these conditions, but which, although subject to the risks referred to, had not produced any evil results. Probably the Author, by enforcing an unreasonably high standard of purity, would create some of the evils which it was sought to prevent. If only water from deep subterranean sources or from streams above suspicion of contamination were to be used, a less abundant supply would be available than was now employed. The limitation of supply would arise from two causes, one being the difficulty of obtaining the necessary quantity of underground water, and the other being the cost of getting it. Where the cost of supplying a town was attended with heavy water-rates, Mr. Robinson had found that the authorities were disposed to restrict the quantity used for sanitary purposes, such as flushing sewers, road watering, and the like. Such restriction would lead to insanitary results. The alarmist views entertained by the Author were not supported by practical evidence. If the germs of contagious diseases had the vitality and produced the mischief alleged, the evils attending the use of water subject to their influence would have been manifested. Without wishing to underestimate the risk of transmitting diseases by water, Mr. Robinson would expect to find some proof of the allegation in the case of a city like London. Obviously the water supplied by the metropolitan companies which took their supply from the Thames must be placed in the class of water of the dangerous kind; no contagious diseases however could be traced to its use. Frequent attempts had been made to connect cases of typhoid and similar diseases to the use of water supplied from the Thames, and he had on several occasions been engaged in examining into such cases. He had found (and the experience of others was to the same effect) that where water had caused illness it had been solely through the foul state of the cisterns and receptacles for storing it. The presence of filth of various kinds and dead animals accounted for the mischief. A constant supply would remove this cause of danger.

Another view of the subject was worth referring to. Supposing Mr. Robinson's view that water perfectly free from suspicion was to be insisted on for dietetic purposes, a duplicate supply would be required in many cases, such as has been proposed for London. Were this system to be adopted the inferior water would most probably be less pure than that previously supplied, inasmuch as it would be thought unnecessary to filter water intended to extinguish fires, water streets, or cleanse courts and alleys. The germs of some contagious diseases were, according to the best medical authorities, even more capable of being introduced into the human system through the lungs than through the stomach. If, therefore, the dangers apprehended were really based upon reasonable grounds, the air instead of the water might become the medium for conveying the disease germs under the state of things that would then exist. Much inconvenience had been experienced by engineers, owing to analytical chemists adopting different terms to express the results of their analyses. Mr. Robinson was continually having to deal with analyses in which similar impurities were described by different chemists in different terms. The adoption of a uniform nomenclature would be both convenient to those who had to act upon the results of chemical analyses, and would also remove one of the several grounds of difference that appeared to exist amongst chemists themselves.

Mr. JOHN TAYLOR observed that the Lambeth Water Company Mr. Taylor had opposed the establishment of the Lower Thames Valley Joint Sewerage Board's proposed sewage farm at Molesey, on the ground that the source of their supply of underground water would be polluted, in consequence of the immense volume of sewage intended to be put on the land. It was contended on behalf of the Joint Board that this underground water was nothing but "Thames river water filtered through a stratum of porous gravel." Samples were obtained from Abyssinian pumps sunk on various parts of the proposed sewage farm. The whole question was investigated by Mr. J. T. Harrison, M. Inst. C.E., and Captain Hildyard, R.E., who were appointed by the Local Government Board, and whose inquiry lasted forty-five days, and who both agreed in a report from which he would quote.

The importance of this report would warrant the length of the quotations. In the letter from the Secretary to the Local Government Board to the Clerk to the Lower Thames Valley Main Sewerage Board, dated the 8th of November, 1880, intimating that "the Board in discharge of their public duty feel themselves unable to grant the Provisional Order applied for," it was stated:

Mr. Taylor. "The question whether the Lambeth water-supply would be affected by the sewage is one of considerable importance and of no less difficulty, the evidence upon this point being very conflicting. It will be seen that the inspector is distinctly of opinion that when the pumps are at work, the subsoil water does travel in the direction of the proposed farm towards the intake of the Lambeth Company, and evidence was adduced to show that several wells were affected by the pumping at the Lambeth works, and some of them were within a quarter of a mile of the farm. In the inquiry the Joint Board offered to construct a puddle-wall to prevent any flow of water from the farm towards the Lambeth wells; but this wall would only extend along the west and part of the north sides of the farm, and probably could not be relied upon in case of floods.

"It is at least doubtful, therefore, whether the irrigation of a large quantity of sewage of so extensive an area of land so near the water-supply would not affect the particular source of water-supply referred to, and the Board would incur very grave responsibility if it sanctioned a scheme which might prejudicially affect the supply of any part of the Metropolis."

In the Report to the President of the Local Government Board on the petition from the Lower Thames Valley Sewerage Board, dated the 21st of May, 1880, Mr. Harrison stated:

"The objections of the Lambeth and other Water Companies demand serious attention. The contention of the Lambeth Company is that they are empowered under their Act of 1851 to draw water from the Thames at Thames Ditton, and that by their Act of 1871 they have power to draw water from the subsoil of their property at West Molesey, as well as from the Thames at the same place; further that they may have occasion to draw water from the Thames at Ditton, and that they actually draw water from the subsoil at Molesey, that the source of supply in these cases would be polluted by the establishment of the proposed sewage-farm, and that to avoid such pollution the Joint Board should not be permitted to bring the sewage of the district to the proposed land.

"To show that the Joint Board considered this contention not frivolous, it is sufficient to state that they proposed to insert a clause in the Bill presented to Parliament in 1879 requiring every water company compulsorily to close their intakes below the confluence of the rivers Mole and Embur with the Thames, and in the inquiry they expressed their willingness to construct

at a cost of £25,000, from the sewage-farm to a point below Mr. Taylor's Thames Ditton, if, in my opinion, it was desirable to do so. They also proposed to construct a puddle-wall for a length of about 3,000 feet along the western and northern sides of the proposed farm, at a considerable cost (variously estimated at from £5,800 to £10,000), with the express object of preventing the water from the farm flowing underground to the intakes of the Lambeth Water Company. It is true that both Colonel Haywood, who designed the scheme, and Sir Thomas Nelson are of opinion that the construction of this puddle-wall is unnecessary, and they deny the assertion that the Lambeth Company draw any water from the subsoil; but I have no doubt as to the fact that they do draw very largely from the subsoil source, and it is difficult to suppose that this source would not be prejudiced by the proposed sewage-farm. I do not believe that the puddle-wall would protect the water company against the pollution of their underground source of supply, more especially during floods and in very wet weather, when they draw most largely from this source.

"In my opinion the interests involved in this question of subsoil water-supply are of much greater importance than they would be if they affected only the Lambeth Water Company and those inhabitants of London to whom they supply water.

"The Lambeth Water Company laid down perforated pipes parallel to the River Thames along the frontage of their premises, evidently with the expectation that they would thereby take advantage of the natural filter formed by the gravel and sandbeds intervening between the Thames and their pipes, and would thus obtain a supply of Thames water naturally filtered, and would thereby diminish materially the expense and difficulty of filtering the water sufficiently for delivery in London. The result is that they have for some years drawn about 10,000,000 gallons per day from this source, the remaining 6,000,000 gallons daily supply being taken directly from the Thames. The water thus derived from the subsoil is beautifully clear, and the advantage of having this source of supply during floods is very great, at the same time the analyses of the water supplied by the Company for several years past prove that its quality has been improved.

"The Joint Board and the Lambeth Company have taken a great deal of trouble during the inquiry to ascertain the source whence this subsoil supply was derived, and after giving all the ascertained facts great consideration, I am of opinion that probably more than half of the supply is derived from the land and less than one-half from the Thames.

Mr. Taylor. "If this be so, I need only mention the reply given by Dr. Frankland to the following question:

"*Question.*—Assuming that the sewage of 330,000 people is to be put on this area of land, and that the Lambeth Company are pumping within a mile . . . do you consider that there would be risk of infection by the fact of that water being afterwards drunk?

"*Answer.*—Undoubtedly; and if I had found that the subsoil water could by any possibility have been pumped then, I should not have been here to-day to advocate the scheme (of the Joint Board).

"Dr. Frankland was a witness for the Joint Board.

"It is true that, after further investigations and analyses taken by him, Dr. Tidy, and Dr. Voelcker, he came to the conclusion (*vide* joint report) that:

"'Without saying that no subsoil water whatsoever finds its way to the pumping station of the Lambeth Company, it is evident, for all practical purposes, that the water pumped by the Company is nothing else than Thames river-water, filtered through a stratum of porous gravel.'"

"This conclusion was based upon a comparison between the average analyses of the Thames and well-water and of samples taken from the subsoil at the farm. The mistake of thus considering the question was clearly shown in the examination of Dr. Tidy, who presented the report; and a comparison between the average analyses of the Thames water and of that taken from the farm, and the analyses of the well-water proved clearly to my mind that at least one-half of the well-water pumped by the Lambeth Company is from the land. Mr. Michael, in his reply, admitted that Dr. Tidy's evidence proved 'that the water which was in the well could not come entirely from the Thames without any other source.' At the same time he denied that it comes from the direction of the farm. I have carefully considered the question, and I am satisfied that the subsoil water does travel from the direction of the sewage-farm to the Lambeth intake.

"I cannot pass without notice the question of whether it is not very desirable that this subsoil source of water should be largely taken advantage of for the supply of London.

"The quality of the water is of first importance—upon this question the chemists differ widely—

"Dr. Frankland says, 'I should rather prefer the Abyssinian pump water (taken on the sewage-farm) to the Thames water, either taken directly from the Thames or from

the pumping well of the Lambeth Company for domestic Mr. Taylor. purposes,' 'on the ground that it contains, on the whole, a smaller proportion of organic matter; it is not much harder, and there is no excessive quantity of solid matter in it;' again—'If the Lambeth Company could get water of the quality that we obtained from these Abyssinian pumps it would certainly be an advantage to supply that water to London in preference to Thames water.'

"On the other hand, Dr. Tidy says, 'I should object to subsoil water being used for the supply of London,' and he could not agree with Dr. Frankland in the above opinions, as he considered one sample of water had 'a certain shadow of suspicion that would make him hesitate to speak so confidently of that water as Dr. Frankland did;' again, Professor Wanklyn says, 'The water (from the Abyssinian pump on the farm) was remarkably pure; it was the purest water next to deep spring-water that I ever met with.'

"If this subsoil water be as pure as Professor Wanklyn and Dr. Frankland represent it, and a source of supply for London preferable to the river Thames, it becomes a matter of very great importance to ascertain the gathering ground from which this supply is derived, the probabilities of its being polluted, and the quantity of water which may be derived from it.

"At the commencement of the late inquiry a geological map of the country to the westward of the sewage-farm was prepared at my request. This plan showed the outcrop of the London Clay between Richmond and Ealing on the east, and the neighbourhood of the Winchfield Station on the west. The London Clay seems here to form a complete basin, within which lie deposited the Bagshot sands to the westward and Thames gravel to the eastward. The area of the basin thus covered is 200,000 acres, and it may be described generally as formed of exceedingly permeable materials, such that the rain rapidly disappears from the surface. The basin is traversed by the Blackwater, the Wey, and the Mole from south to north, and by the Thames flowing from west to east. I am not certain, but it appears probable that the former rivers carry off but little of the rain falling within the basin. The map above referred to was submitted to the late Professor Ansted, and he gave it as his opinion that the Bagshot sand formation is the gathering ground for the underground river at Molesey. The population on the Bagshot sand formation is very sparse, and the area, taken as a whole, is not liable to serious pollution. Ten

Mr. Taylor. inches of rain sinking into the ground over the entire area would probably yield annually a larger volume of water than is at the present time delivered to London by all the water companies which take water from the river Thames.

“The views above expressed are given as approximations only to the truth, but they are of sufficient importance to justify further careful investigation into their accuracy; and if they are correct every means should be taken to prevent the pollution of this valuable subsoil water.

“Dr. Tidy and others have expressed strong objections to the use of subsoil water for the supply of London. I do not admit the validity of their objections; were this water contained in a basin of gravel, with numerous sources of pollution on the surface, and the water itself stagnant, I should heartily concur in them, but it is not thus in this instance. The area of gathering ground is very extensive, remarkably free from pollution, and the water is constantly flowing through underground channels of sand and gravel to the lowest part of the basin, viz., the neighbourhood of Thames Ditton, where the issue, at one time, of water above the level of the river has apparently given the name ‘Seething Wells’ to a spot near the Thames.”

Other statements had been made by Mr. Jabez Hogg as to the Lambeth Company. For instance, he said: “It had apparently not entered into the calculation of any one, that in drawing subsoil-water from an area of some extent (in this instance radius of more than $1\frac{1}{2}$ mile) the whole incidence of that area must be taken into account. Now, it so happened that at West Molesey it included seven hundred and seventy cesspools, all of which were pumped dry, and mixed in with the Company water. A Government investigation ended in putting a stop to that objectionable mode of drawing a supply of ‘spring-water’ (p. 93). On this Mr. Taylor might remark that the preceding quotations from the Government Inspector’s report showed that not only was the drawing of this spring-water not put a stop to but that it was considered by him a most valuable and pure source of water-supply.

Moreover, the statement of the number of cesspools was erroneous. He had the number of cesspools carefully counted, and ascertained that within a radius of $\frac{1}{2}$ mile from the pumping engine there were only nine, and within a radius of 1 mile only thirty-nine, making a total within a mile of forty-eight, while the whole number of houses in West Molesey was not more than eighty. If with West Molesey Mr. Hogg meant to include East Molesey, which lay at

distance of 2 miles and upwards from the pumping station, it Mr. Taylor was doubtful whether there were in both places half the number of cesspools which he had stated. But even if there were, it had been conclusively shown during the inquiry that the subsoil drainage flowed towards the north-east, or towards Molesey lock, where there was a fall in the river level of 6 feet. This flow was directly away from the pumping station, and the fact had been commented on in one of the above quotations from the Inspector's report.

31 January, 1882.

JAMES BRUNLEES, F.R.S.E., Vice-President,
in the Chair.

The discussion upon the Paper by Mr. Folkard, on "The Analysis of Potable Water," occupied the evening.

7 February, 1882.

SIR W. G. ARMSTRONG, C.B., F.R.S., President,
in the Chair.

THE following Associate Members have been transferred by the Council to the class of

Members.

DONALD STUART BAYNES.
JOHN BROWN.

WILLIAM BESWICK MYERS.
JOHN MERVYN WRENCH.

The following Candidates have been admitted by the Council

Students.

HENRY CROWQUILL AYRIS.
FREDERICK WILLIAM BACH.
HARRY BROWN BALDWIN.
WILLIAM BATES.
ORIENT BELL.
GEORGE LEWIS BURTON.
EDMUND HENRY BYNG.
FREDERICK HARRISON TOWNSEND CHAMBERLAINE.
NICHOLAS DOUGLASS DOUGLASS.
EDWARD RAWSON GARDINER.
WALTER GILES.

HUGH GRAHAM.
CHARLES EDWARD HANNAFORD.
HERBERT SPONG HAWKINS.
ABRAHAM HEMINGWAY.
ROBERT JARRATT MONEY.
JOHN FREDERICK LAVINGTON NOWELL.
JOHN STEVENS PAGE.
THOMAS GEORGE GRACE PEARCE.
ARTHUR DUNCAN PROUSE.
FREDERICK ROSE.
RICHARD ERNEST SEXTON.
JACOB SWART.

The following Candidates were balloted for and duly elected

Members.

GEORGE MORRISON BARR.
THOMAS MORRISON BARR.
DANIEL MANDERS BEERE.
TOMASO GAUDENZIO BEZZI.
WILLIAM DRENNAN.
The Hon. GEORGE ALEXANDER HALDANE
DUNCAN.

HENRY HAWORTH.
JOHN WILLIAM HENRY JAMES,
JOHN MACRAE.
WILLIAM GREY PEARSON.
ALLAN DUNCAN STEWART.
WILLIAM HENRY WHITE.

Associate Members.

CLEMENT XAVER JULIUS ALLMANN.
 BENTLEY WATSON BEEVER, Stud. Inst.
 C.E.
 THOMAS BERRILL BEWICK, Stud. Inst.
 C.E.
 ARTHUR HENRY CURLING.
 HAY FREDERICK DONALDSON.
 HARRY GREENFIELD DUGUID.
 LUDWIG STEWART RUDOLPH EWING.
 EDWARD HAMILTON, Stud. Inst. C.E.
 JAMES HOLDEN.
 JAMES HENRY COHENWALL LANGDON.
 DANIEL MACALISTER, Stud. Inst. C.E.
 EDWARD GERALD JAMES MCCUDDEN.
 GEORGE JOHN MONSON, Stud. Inst. C.E.
 FRANK CHARLES POWELL.
 SYDNEY PRESTON, Stud. Inst. C.E.
 His Highness PRINCE PRIBITZ.
 EDGAR PHILIP RATHBONE, Stud. Inst.
 C.E.
 ROBERT HENRY READ.

WILLIAM STUART BENDEL.
 DR. ESTEVÃO SAVICH.
 WALTER DOUGLAS SEATON, Stud. Inst.
 C.E.
 CHARLES DE GRAVE SELLS, Stud. Inst.
 C.E.
 KHAN Bahadur BOMANJI SORABJI.
 HENRY LEONARD STABLES.
 ARTHUR MOORE THOMPSON.
 JOHN MILLER THORNTON.
 CARLETON FOWELL TUFNELL, Stud.
 Inst. C.E.
 GEORGE BRAVELEY TYNDALL, Stud.
 Inst. C.E.
 THOMAS HENRY WILLIAMS.
 EDWARD WALTER NEALOR WOOD, Stud.
 Inst. C.E.
 DOUGLAS FITZGERALD WORGER, Stud.
 Inst. C.E.
 JULES DENT YOUNG.

Associate.

Lieutenant FRANCISCO AUGUSTO DE PAIVA BUENO BRANDÃO.

(Paper No. 1839.)

"Candle-Power of the Electric Light."

By PAGET HIGGS, LL.D.

Very diverse statements are constantly before the public as to the candle-power of varying devices affording the electric light. None of these statements appear to be compatible, neither does any law of difference immediately present itself. Just as in a diagram of results the sanguine mathematician may picture to himself the curve representing a definite law where the unimaginative observer can perceive only a chaotic zigzag of dots, so with a little bias there, and a small subtraction here, some order may be evolved from the figures relating to the electric light. Such an attempt is made in what follows.

The most salient point for a unit of comparison is the number of heat-units represented by electrical measurement, as in ratio with

the candle-power measured optically. But at the outset a difficulty or rather an uncertainty, is experienced; this refers, however, only to arc-lights, of which there are two systems of measurement—one system with the carbons on the same axis, the other with the axis of one of the carbons forming a very acute angle with the axis of the other carbon, so that the glowing crater of one carbon forms reflector to the point of the other. In the latter case, considering the light of the former as unity, the light may be about 1·6 time stronger as measured. This has been pointed out by Mr Douglass, M. Inst. C.E., in a Report to the Trinity House. Another source of discrepancy is the want of knowledge of the specific heat of the vapour of the electric arc, and of its temperature, both unknown quantities; if the one were known, the other could be determined.

Taking the ratio of units of heat represented per candle-power, the subsequent figures will show a large margin of economy in arc-lighting over incandescent-lighting. This will of course be true of the arc considered only as a furnace producing a great heat in a smaller space than by incandescence; and it appears to the Author to be true for another reason. Whatever may be the specific heat of the vapour of the electric arc, it is certain that over the given resistance of the arc, as compared with an equal resistance of the incandescent-lamp, the mass of the arc, measured by the molecules it contains, is far less than that of the solid carbon; and the amount of work to be done by the current from this cause will be so considerably less, as to lead to a prophetic renunciation of greater economy of expended energy than is really found.

To return to figures. Suppose a light of 1,000 candle-power measured with the carbons on the same axis, be produced with 4·5 ohms resistance and 10 webers of current, there will be represented 108 gramme-degrees of heat, or nearly 0·1 gramme-degree per candle-power per second. This is deducible from the figures given by the Brush system. It does not include the heat due to consumption of carbon in air, which is inconsiderable.

In a Siemens lamp tested by the Author, about 3,000 candle-power, of diffused beam, was obtained with 36 webers current, when the lamp had 1 ohm of resistance in the arc; this corresponds to 335 heat-units, or $\left(\frac{335}{3,000} =\right) 0·112$ unit per candle-power. In a Serrin lamp, fed from a Gramme machine, the Author obtained light of 3,600 candle-power with 45·7 webers current, the arc havin

$1\frac{1}{2}$ ohm resistance, corresponding to 624 heat-units, or 0·17 unit per candle. A Crompton lamp, fed by a Bürgin machine, gave a light said to be of 4,000 candle-power; but assuming this to be from bi-axial position of the carbons, about 2,000 candle-power would correspond to 180 heat-units for 16 webers on 2·93 ohms, or about 0·09 heat-unit per candle-power. On (about) the same resistance of arc in a Crompton lamp, 24 webers yielded the Author 3,600 candle-power, or about 403 heat-units, corresponding to 0·12 heat-unit per candle-power.

Numerous measurements are recorded, all varying greatly, partly and chiefly because of the variations in the measurements of candle-power. All the measurements, as recorded by the Author, have been made by the same method, from the "diffused beam." Their mean may therefore be taken for comparison with subsequent numbers. It is 0·118 gramme-degree per candle-power.

As 1 gramme-degree = 42 million ergs, 1 candle-power represents 4·9 million ergs. As a foot-pound is 13·56 million ergs, each candle-power represents 0·364 foot-lb. per second, or 1,511 candle-power per HP., a rough check upon the foregoing figures.

The late Mr. L. Schwendler, M. Inst. C.E., has stated in a Paper (fragmentary to the Author) that the standard candle does work at the rate of 610 meg-ergs in a second, whilst the unit of light is produced electrically at the rate of not more than 20 meg-ergs in a second. This latter figure is very high if it refer to arc-lighting; for, although at the trials under the auspices of the Franklin Institute, when only 380 candle-power per HP. were obtained, there were estimated to be $(6\cdot5 \times 0\cdot252 =) 1\cdot6$ gramme-degree = 67 meg-ergs per candle-power, great strides have since been made. Mr. Schwendler's figures are now at a long discount, and would appear corresponding to a still lower state of the art if the figures given by others be correct as to candle-power of the lights. As has been stated, however, the figures given in this Paper are intended to be only intercomparative.

Another type of lamp is the Werdermann, which may be termed an arc-incandescent-lamp, because the light is obtained from the incandescence of a cone of carbon resting at its apex on a negative electrode of larger section, and from the arc that plays between the sides of the carbon-cone and face of the negative electrode. Ten of these lamps, giving 40 candle-power light, each burning 4·5-millimetre carbons, yielded about 0·88 heat-unit per candle-power. A series of these lamps averaged 306 candle-power, with 50 webers current, the resistance of each lamp being 0·1337 ohm. This corresponds to 80 heat-units per lamp, or to 0·262 heat-unit

per candle-power. Thus, where the small light is a sub-multiple to a considerable degree of the larger light, want of economy commences to be evident, and an average can no longer be taken.

A Joel lamp, one of a series of ten, is said to have afforded 32 candle-power, with an electromotive force of 130 volts, sending current of 50 webers through the series, corresponding to 156 heat-units per lamp, or 0.49 heat-unit per candle-power.

These notes, however crude, have more weight when pure incandescent lamps are considered. In this case measurement becomes easy, for the light approximates in colour to that of the standard candle employed, and the resistance of the incandescent fibre is sufficiently constant to yield concordant results.

One of Maxim's earliest lamps was measured by the Author and found to indicate 3.6 ohms when cold, and 1.9 ohm when giving 11.5 candle-power light with a current of 5.5 webers. This corresponds to 0.83 heat-unit per candle-power, or about 140 candle-power per HP. It should be remarked that with this current the loss due to heat per unit of resistance in the conductors would be 3 per cent. as against the 0.1 per cent. for a weber-current. Another Maxim lamp of about 64 ohms when giving 50 candle-power, and 116 ohms when cold, with 1.3 weber-current, would correspond to 0.52 heat-unit per candle-power. An Edison lamp in the Author's possession, measures 61 ohms when cold and 33 ohms when hot, and indicates, with 1 weber of current, 11 candle-power equivalent to 0.73 heat-unit per candle-power.

A Swan lamp had not, at the time of the Author's measurement, found its way to America; but there are several statements as to the candle-power of this lamp. It would appear that with 160 volts and 24 webers of current, twenty-four rows of two lamps in series or forty-eight lamps, each of 84 ohms resistance, gave 48 candle-power each. Assuming that this was the resistance of the lamp when cold, that the resistance when incandescent would be 33 ohms and that there would then be 2 webers passing through each lamp, this would correspond to 0.66 heat-unit per candle-power. These are, however, assumed figures.

It should be clearly understood in estimating the work done by any carbon focus that the resistance of the carbon decreases with increase of temperature, and that, if the current be directly taken from a dynamo-machine, constructed on the mutual accumulation principle, there will be considerably more current flowing through the lamp than an estimate based on a potential measurement would allow.

The following Table furnishes a comprehensive view of the results obtained. (The figures are only roughly calculated.)

TABLE I.

Actual Diffused Light in Focus.	Candle-power per HP. in Focus.	Gramme- degree per Candle-power per Second.	Foot-lbs. per Minute per Candle- power.	Remarks.
1,000	1,774	0.10	III	Arc. Brush.
3,000	1,650	0.11	20	" Siemens as found.
3,600	1,090	0.17	32	" Serrin.
3,600	1,500	0.12	22	" Crompton.
..	1,500	0.12	22	" (Mean.)
40	200	II	104	" Incandescent.
306	684	0.26	48	" Werdermann.
306	363	0.49	91	" Joel.
11½	214	0.83	154	Incandescent Maxim.
50	280	0.64	119	" "
50	345	0.52	96	" "
11	245	0.73	186	" Edison.
48	270	0.70	123	" Swan estimated.

It is at present impossible to estimate the loss due to decrease of resistance in the carbon by expenditure of heat, but it must be considerable.

The Author hopes that from this it will appear in how far the incandescent-light is theoretically more costly than the arc-light, as about 6 to 1. But in practical use there are other considerations, not the smallest of which is the attendance arc-lights require to maintain their store of carbon.

The light employed in ordinary domestic avocations is approximately 1 candle (standard) at 1 foot distance. Assuming an average distance of 8 feet for domestic lighting, the electric chandelier must be of 64 candle-power to give the same "surface-intensity," in a room 16 feet square and of slightly more than ordinary height. The incandescent-lamp will give this light at an expenditure of 0.6 heat-unit per candle-power, or 38.4 heat-units per light-centre, or say four chandeliers per HP.

A 5-feet gas-burner supplying 16 candle-power light would cost for a 4-light chandelier, for 20 cubic feet of gas, in New York $\$2.50 \times .02 = \0.05 or 5 cents an hour. At $\$40$ a year cost, or adding 25 per cent. for profit, at $\$50$ a year, 1 HP. can be had for about 300 working hours a year; and $\frac{5,000}{300} = 16.6$ cents

an hour, or $\frac{16.6}{4} = 4.15$ cents per hour for the electric chandelier.

This shows that, even now, were a reasonable commercial profit

taken, the electric light, in the United States at least, co compete with gas.

A Paper by Sir William Thomson and Mr. Bottomley, entitled "The Illuminating Powers of Incandescent Vacuum Lamps with Measured Potentials and Measured Currents,"¹ read at the meeting of the British Association, contains a Table from which a valuable law can be deduced, a law that the Author first enunciated before the Institution in 1878. It is that the light in an electric system varies as the fourth power of the current whose resistance or potential is constant, or as the second power of the work done in the circuit. To illustrate this columns *a*, *b*, *c* and *d* have been taken from the Tables in the Paper referred to, and *e* and *f* calculated. The agreement is sufficiently close.

The value of the candle-power in heat-units is higher than that observed by the Author, and this is probably due to the method employed in measurement of the light, which is more wasteful than the observed rays than that used by the Author.

The law just referred to is illustrated by the following Table:

TABLE II.

<i>a.</i> Volts.	<i>b.</i> Webers.	<i>c.</i> HP.	<i>d.</i> Candles.	<i>e.</i> Observed Ratio of Light.	<i>f.</i> Estimated Ratio of Light.
56·9	1·21	0·093	11·6	1·00	1·0
65·5	1·46	0·129	25·0	2·16	1·9
70·2	1·64	0·156	42·0	3·62	2·8
74·1	1·81	0·181	44·0	3·79	3·9
76·1	1·82	0·187	55·0	4·75	4·1
78·0	1·99	0·210	63·0	5·42	5·2
80·3	2·06	0·224	66·0	5·70	5·9
81·9	2·06	0·228	76·0	6·54	6·2
84·6	2·06	0·235	82·0	7·05	6·5
87·0	2·10	0·247	84·0	7·24	7·2
90·9	2·17	0·267	102·0	8·80	8·4
99·1	2·21	0·296	114·0	9·85	9·8

Considering that in the measuring galvanometer, although a very accurate instrument, the deflections are merely proportional to the effect, the liability of error will be small; and that in the photometer used (an inaccurate instrument) the measurements vary with the second power of the distance, whilst the light under measurement varies with the fourth power of the current, the departure from agreement of the observed and estimated figures may be fairly ascribed to errors of observation.

¹ Vide "Nature," vol. xxiv., p. 490.

Discussion.

Mr. J. W. SWAN remarked, through the Secretary, that even Mr. Swan. the material was not as large, nor the conditions, under which the observations were made, as perfect as could have been wished, the Paper at least formed an interesting contribution on a difficult and important subject. He doubted, however, whether the facts adduced were sufficient to establish, or even to strongly support, the theoretical views expressed, more particularly with regard to the comparative economy of the arc-light and of the incandescent-light. He failed to see why it might not be possible to obtain as large an amount of light for a given expenditure of energy invested in a series of incandescent-lamps as in an arc-light. It was perhaps not possible to raise the carbon filament of an incandescent-lamp to quite the same degree of intense brilliance as the crater in the positive electrode of an arc-lamp; but there was full compensation for the somewhat lower incandescence of the carbon filament in the large radiating surface obtained through a multiplication of such filaments. He had seen produced by incandescent-lamps the light of between 2,000 and 3,000 candles by the expenditure of 1 HP. He did not say that the lamps were durable at the exceedingly high temperature to which it was necessary to heat the filaments in order to obtain this result; but that was a practical consideration, and he merely submitted the fact, as bearing upon the theoretical view sought to be established by the Tables. He noticed a discrepancy in the figures on which the calculation of the HP. product of light from Swan lamps was based. It was stated that there were twenty-four rows of lamps with two lamps in each row, that the light given by each lamp was 48 candle-power, that the current was 24 webers and the potential 160 volts. The resistance of the lamps cold was mentioned, but the resistance hot was assumed, and this assumption was supposed to introduce an element of uncertainty into the calculation. But if the current and the electromotive force were known, and both these were stated, the one as 160 volts and the other as 24 webers, that was 1 weber through each of the twenty-four lines, and therefore through each lamp—a current more likely to be correct than the 2 webers also mentioned, and which presupposed a total current of 48 webers instead of 24 given as the total; then it followed, that the light per HP. was 438 candle-power, and not 270, as given in the Table of measurements. Probably it had been overlooked that as two lamps were in series, the 160 volts electromotive force, and

Mr. Swan. 1 weber current, lighted two lamps, and that the united light of the two must therefore be taken as the product of this expenditure of energy. Whether this was the correct explanation of the error or not, it was certain that with the correction he had suggested the result was much more concordant with numerous other measurements. Referring to the remark, "that from this it will appear how far the incandescent-light is theoretically more costly than the arc-light, as about 6 to 1," he would only add, that it appeared to him that a much broader basis of observation than that supplied by the Tables of measurement contained in the Paper was required to support the theory sought to be erected upon it.

Mr. Wilde. Mr. H. WILDE observed, through the Secretary, that in considering that part of the Paper which related to incandescent lighting, the following observations might perhaps be found useful. In the various accounts and descriptions of this method of lighting which had appeared from time to time, a striking feature was the absence of any precise information as to the amount of disintegration of the carbon filament during the transmission of the electric current, and on which the durability or life of the lamp depended. The determination of this question, as would be obvious, preceded all others in order of importance, when the new method of lighting was compared with other illuminants in point of economy and convenience. From experiments which he had made, with Swan's lamps of the most recent manufacture, he had found that the carbon filament, after being maintained at the parliamentary standard of a single gas-light of 16 candle-power, broke down in one hundred and forty to one hundred and fifty hours. In these experiments care was taken to maintain the light as nearly uniform as possible, and the comparison was made with Rumford's photometer and a standard wax-candle. After the lamps had been lighted for some hours, a deposit of carbon was formed in the interior of the glass globe, which was attended by a visible diminution of the thickness of the carbon filament. This deposit increased in density sufficient to diminish the available light from the filament by 3 or 4 candle-power before it broke down. The depth of coloration of the glass globe afforded a ready means of estimating, approximately, the number of hours which a lamp had been in operation at a given candle-power. Further observations indicated that the durability of the carbon filament of incandescent-lamps was inversely proportional to the square of the luminous intensity. Hence, the life of a carbon which lasted one hundred and fifty hours at a power of 16 candles, would be extended to six hundred hours at a power of 8 candles; while with

power of 32 candles the life of the carbon would be diminished Mr. Wilde. thirty-eight hours. It would therefore appear that this lamp is only practicable for light below 16 candle-power. There was no reason to expect a better duty from other incandescent-lamps in which a carbon filament was used than was obtained from the Swan lamp, as the metallic lustre and ring of the filament in this lamp showed that the conversion of the hydro-carbon, of which it was composed, into pure carbon, had been complete. The determination of the durability of the filament of an incandescent-lamp thus afforded a basis of comparison with other methods of illumination in point of economy. Now, 750 cubic feet of standard, or 16 candle-gas, were the equivalent of the life of a Swan lamp of the same illuminating power for one hundred and fifty hours, which, with gas at 3s. per 1,000 cubic feet, the price in London, amounted to 2s. 3d. for the same amount of light for one hundred and fifty hours as from a Swan lamp. In this sum was included the cost of manufacture, distribution, and profit on the gas, which was not more than the manufacturing cost of renewing the incandescent-lamp alone. He left untouched the subject of the generation, distribution, and subdivision of the electricity for lighting incandescent-lamps over large areas, as it was attended with so many difficulties, electrical and mechanical, that all comparison with regard to cost would be purely hypothetical; but which, even if these difficulties were overcome, would place the cost of incandescent-lighting largely in excess of the cost of gas-light. While viewing, as he did, the substitution of incandescent- for gas-light as a retrograde step in general domestic and public lighting, there were special applications of the new illuminant which were of undoubted value. The lighting of the interior of steamships by incandescent-lamps had so far been attended with very promising success; but in this case considerations of cost were far outweighed by the superior advantages of comfort and convenience which the new illuminant afforded over oil-lights, for which it was substituted. Other uses would without doubt be found hereafter for incandescent-lighting; and although its application might not be so universal as the promoters of it anticipated, the invention promised to be a permanent and valuable addition to the resources of artificial illumination.

Mr. H. E. JONES said, although no professed electrician, he had Mr. Jones. nevertheless been struck with what seemed to him to be two fallacies in the Paper. First, the Author appeared to assume that there was a distinct ratio between the heat-units observed and the amount of light given. That was certainly contrary to his experience of

Mr. Jones. photometric experiments with other lights. In fact, with regard to gas-lights, it was exactly in the inverse ratio, for the most heat from gas-light was coincident with the worst illuminating power. That part of the Paper, however, with which he found most fault was an error in the statements which had been made from time to time about the electric light, and which in his view discredited those connected with it. An attempt was made to draw a comparison between the cost of the electric light and that of gas, but in estimating the cost of the electric light the Author stopped short at the HP. cost of production. In the Appendix to the Report of the Electric Light Committee, June 1879, p. 243, it was stated that of the total cost, 37·11 francs, of a certain number of lamps, something like 31 francs attached to the carbon, altogether independent of machine and HP. In the present case the Author had taken the cost of gas at 2½ dollars per 1,000 cubic feet in New York, and to compare the cost of the electric light with that, there must be added expenses of distribution, management, wear and tear of machinery, and interest upon capital, which altogether was no very small item. The published accounts of a large Metropolitan Gas Company showed that the rates and taxes, the collection and the making up of the accounts in the office, the distribution expenses, cost of inspecting the lighting, and so on, came to three quarters of the net cost of material for the gas, deducting the product received from the coal used. When the advocates of the electric light had obtained a business, which they had not at present, they would be confronted with these expenses; they would also be confronted with the dividend payable to their shareholders, which would have to be met by a balance at the bank, and not by bills and promissory notes, paid for the assumed privilege of lighting some other part of England with a light which, as shown in London, made outsiders think that it was a commercial success. It had been shown in the streets of London; the misguided foreigner came over and thought that the City was being lighted in competition with gas in the most successful manner; the figures of cost were kept out of sight; and the foreigner went and bought a concession of some patent for electric lighting. That was a profitable operation. He did not wish to wander from the precise subject, but he spoke essentially as a gas engineer. It was said when the electric light was first brought into London that there would be seen on the Embankment lights of 1,000 candle-power, but what was the result? It was found, when tested with the photometer by Mr. Keates,¹ that the light was only

¹ *Vide* Report to Metropolitan Board of Works, May 1879, p. 11

0 candle-power. If any gentleman drove over London bridge Mr. Jones. a dark night he would find the passage a difficult one; he had ide it constantly, for the purpose of observing the electric light- g, and the conclusion in his mind was that the lighting of some rts of the City now, practically by the Electric Light Com- nies, was a ghastly failure. That it was a very extravagant one as proved by a document printed by the Common Council, show- g the tenders for electric lighting in the City of London, and roving that it was costing for current expenses three or four mes as much as gas; and when the expenses of wear and tear, ad so forth, were added, it would be seen what a costly thing lectric light was. The Author appeared to have written the aper for the purpose of bolstering up the electric light at the xpense of gas, and claimed for it that which Mr. Jones did not esitate to say, and which every one practically acquainted with he carrying on of a commercial undertaking on a very large scale would know, was only a fraction of the cost, viz., the HP. of developing the light. No confidence could be reposed in such a comparison. There should have been added the carbons, the wear and tear of the machines, which were running eight hundred revo- lutions per minute, the original cost of the plant, the depreciation, which, with machinery running at that speed, was 15 to 20 per cent. per annum, and also the managerial and general expenses, which, as shown in the case he had quoted of a Metropolitan Company, where the rates and taxes alone amounted to 30 per cent. of the net cost of the gas for coals, after deducting the value of the products. One other point he wished to notice was this: a great deal had been said of what light could be developed from 1 lb. of coal burnt on the bars of a steam-engine developing electric light, and it was assumed that that was something enormous compared with what the gas engineer made of it. Now he wished to say that 1 lb. of coal could not be treated more economically than by the gas engineer. He took it, distilled it analytically, brought out the fixed, gaseous, and liquid carbons, and then returned a fuel out of the coal which was essentially the fuel of the poor; and besides that, he got the light, and many other things. There had also now been obtained something approaching to a good gas-engine, and it had been found that gas used in that way was really more effective than the coal burnt under the boiler. Therefore all the exaggerated contempt that was poured by ignorant people upon gas, as contrasted with the electric light, was very much misplaced. There was much ignorance abroad; he was guilty of it himself to some extent with

Mr. Jones.

CITY of LONDON—ELECTRIC LIGHTING, 1880.

Abstract of tenders received by the Streets Committee of the Commissioners of Sewers on the 28th day of October, 1880, for lighting the thoroughfares Bridge Street, Ludgate Circus, Ludgate Hill, St. Paul's Churchyard (North side), Cheapside, Poultry, Mansion House Street, Royal Exchange (open in front of), King William Street, Adelaide Place, Queen Street, Queen's Place, Queen Victoria Street, King Street, Guildhall Yard, London Bridge, Southwark Bridge, and Blackfriars Bridge.

Name of Contractor Tendering.	To Light for 12 Months, from Sunset to Sunrise.	To provide and fix Machinery, Lamps, &c., and remove same at expiration of Contract.	Total Cost of 12 Months' Trial.	Number of Electric Lamps to be Lighted.	Number of Lamps Lighted Electrically.
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District No. 1.—Comprising Blackfriars Bridge, New Bridge Street, Ludgate Circus, Ludgate Hill, St. Paul's Churchyard (North side), and Cheapside (from Western end to King Street):—

Anglo-American Electric Light Company ("Brush" System).	£ 660 abt. (same price as Commission pays for gas.)	£ 750	£ 1,410	32	150 abt.
Crompton & Co.	2,007	500	2,507	17	152
Electric and Magnetic Company ("Jablochkoff" System).	1,500	1,550 ¹	3,050	48	144
Siemens Brothers	2,050	1,650	3,700	29 (viz., 23 small, 6 large.)	144

District No. 2.—Comprising Southwark Bridge, Queen Victoria Street, and Upper Thames Street (between Queen Victoria Street and Upper Thames Street):—

Anglo-American Electric Light Company ("Brush" System).	..	No tender			
Crompton & Co.	2,167	560	2,727	16	176
Electric and Magnetic Company ("Jablochkoff" System).	1,580	1,350 ¹	2,930	52	161
Siemens Brothers	1,850	980	2,830	31 (viz., 26 small, 5 large.)	164

District No. 3.—Comprising London Bridge, Queen Street (between Queen Victoria Street and Cheapside), Cheapside (between King Street and Poultry), King Street, Guildhall Yard, Poultry, Mansion House Street, Royal Exchange (open space in front of), King William Street, and Adelaide Place.

Anglo-American Electric Light Company ("Brush" System).	..	No tender			
Crompton & Co.	2,475	650	3,125	18	132
Electric and Magnetic Company ("Jablochkoff" System).	..	No tender			
Siemens Brothers	2,270	1,450	3,720	32 (viz., 26 small, 6 large.)	138

¹ Should the Commission determine to have the conductors laid underground, the addition for each district will be £2,000, and £2,000 more for removing them and making good after. N.B.—The black figures are not in original, but represent about the cost of the gas lighting.

to electricity. As he had frequently replied to people when Mr. Jones had asked him upon the subject, electricity, as applied to gas and to power, was analogous to water which was pumped from an accumulator under pressure, and liberated through the other machine, being a transmitter of energy and not an original power, which could be gathered anywhere, and turned at the service of man. He would like to direct the attention of the members to the article on the subject of the cost of the Electric Light in "The Engineer" of the 13th of January, 1882.

R. E. CROMPTON observed that it had been pointed out how Mr. Crompton could obtain a cheap source of power by using the gas itself, and their attention had been called to the point, that with the primary object of supplying the public with light, by means of which manufacturers obtained secondary products of importance, equal to, in fact, almost greater than the gas itself. He thanked Mr. Jones for this; in future electric light engineers would have to obtain all the useful residual products from their light by the ordinary process of distillation, and simply use the means of obtaining motive power for producing the electric light. He had, however, prepared a few notes on a different part of the subject, namely, the purely scientific question of the candle-power of the electric light. He noticed that almost at the commencement the Author confessed that but little was known of the specific heat of the vapour of the electric arc and of its nature. This admission had greatly disappointed him, as from his own observations he had long since formed an opinion as to the candle-power of the electric light, whether the arc-light or incandescent-light, was a function of, or at all events closely connected with, its temperature, and from the title of this Paper he fully expected some information on the point. In incandescent-lamps the relation of temperature to lighting power was self-evident, as the temperatures were comparatively low, and the changes in colour, and the changes in temperature, could be followed by the eye. With the arc-light it was different. The greater intensity of light made it difficult, and almost dangerous, to observe it, and it was only by the use of the spectroscope, or by similar means, that changes of these exalted temperatures could be observed. The Author had unnecessarily complicated the matter by introducing the regulating arc-lamps themselves. They occupied but a very small part in obtaining high efficiency in candle-power from an electric current. So long as they held the carbons firmly in place and fed them together with due regularity, so as to maintain a constant difference of potential on the two sides of the arc, they

Crompton. did all they could towards this efficiency. What had mainly to be looked to was the obtaining of a higher temperature at the arc and this by perfecting the carbon rods. The carbon rods must excel in two main points; first, they must be extremely refractory and infusible, in other words, be pure, and free from even the smallest percentage of material more easily volatilizable than the carbon itself. Secondly, they must be hard, dense, and compact so as to oppose as much resistance to the disintegrating action of the current as possible, thus necessitating the much-desired extreme temperatures. The wide discrepancies noticed between different photometric measurements of the same electric light system, were mainly due to the differences in purity and density of the carbons. Pure carbons of little density, or dense carbons containing considerable impurity, were equally adverse to high candle power. Carbons had been moulded from absolutely pure carbon yet of loose texture, which would not afford anything more than a pale blue light of 50 or 60 candles, when a 20 ampère current was used, and almost equally bad results had been given by well-made dense rods, containing not more than 5 per cent. of lime, soda, and other ash. Moreover, the same rods varied considerably from inch to inch, and this would often account for the great changes in brilliancy observable in the arc-lights in public use. The blame for the variation in the light was generally visited on the lamp machines, or engine, but nowadays the blame ought to rest far oftener on the carbons alone. If, as they burnt away, a point was reached where the purity and density exceeded the average, the temperature and the light were greatly increased, and a corresponding decrease in purity or density would greatly diminish the temperature and light. The light given by a pair of carbons in an arc-lamp would vary 60 to 100 per cent. from this cause alone. This change in the light-giving efficiency during the burning away of a single pair of carbons, and consequent wide fluctuations in the photometric readings, had been the cause of endless trouble to observers. The generator of the current, the lamp, the photometer, the difference of colour between the arc-light and standard-light and lastly the observer himself, had all been objected to. It was uncertain what the Author meant by "axial" and "bi-axial" measurements. Probably, however, he meant what was ordinarily termed horizontal and angular measurements. A strong protest ought to be raised against the absurdity of taking horizontal photometric measurements of continuous-current arc-lights. There was no reason why experimenters should continue making and publishing them without the corresponding angular measurements, unless

as that the latter were a trifle more difficult to obtain ; but even that could be easily avoided by inclining the lamp when taking the photometric readings. At any rate, the commercial efficiency of light was always taken at the angular measurement, for the simple reason that as all large centres of light, such as electric arc-lamps, must be placed high up, in order to avoid floor shadows, the light below the horizontal plane were of the greatest commercial value. This angular measurement was at least 80 per cent. in excess of the horizontal one, and it was eminently unfair to compare the electric arc, measured thus horizontally, or at its point of lowest commercial efficiency, with the incandescent electric, or any other source of light, the efficiency of which was nearly equal in all directions. The introduction of heat-units into calculations of the candle-power efficiency of the lamps seemed to be unwise, and likely to lead to confusion. Surely the expression "candle-power per HP." was sufficient to compare the lighting power with the energy. Talking of "Gramme degrees per candle-power" seemed like saying "minutes per ounce." In the table where the arc-lamps were compared with incandescent ones, the arc-lamps were deprived of the 80 per cent. due to the angular measurement not being taken, whereas the average candle-power of the incandescent-lamps was put at 271 candles per HP., instead of 180 candles, which was certainly the maximum efficiency obtained from such lamps up to the present time, under actual conditions of safe working. With these corrections the efficiency of the arc-lamps, compared with that of the incandescent ones, became as 18 to 1. Wide as this gap was, it could not be hoped materially to lessen it, considering that the temperature of the arc-carbons was that of incandescence and destruction, whereas that of the incandescent lamps must not be sufficient to soften, or even change, the form of the delicate carbon filaments.

Mr. W. Sugg wished to offer a few observations upon a different point to that referred to by Mr. Jones. The Author appeared to have taken the cost of gas in New York, when he might just as well have taken the cost of gas in England. The cost, however, was a matter which must be worked out in practice, and if it was found that the cost of the electric light would be very much greater than that of gas, it probably would not be so much employed as gas. That, however, might be left to the future. The part of the Paper with which he wished to deal was the first point, namely, the standard sperm candle. The Author asked what was a sperm candle, and he had pointed out that the light of a sperm candle was that which would be given from the candle

Mr. Sugg. 1 foot all round the light. That was a very good way of pressing a sperm candle, because it was practically what could be got out of it for use, for reading or for work; but unfortunately it was not the standard looked upon by Parliament as being the standard sperm candle. The light of a standard sperm candle was the light given from a point in the centre of a candle, and the calculations with the photometer were made upon that assumption, that the point of light in the centre of the candle was the whole of the light of the candle. He had found it practically an extremely difficult thing, with such an arrangement as that, to carry out experiments and calculations with regard to light over various areas, because with that theory to deal with, viz., that the central point in the candle being the whole of the light, it was evidently a difficulty, when it had to be worked out for estimating the degree of illumination of areas. The plan which the Author proposed, of taking 1 foot round the candle for that purpose was a good one, and could be usefully adopted for many purposes. As he had pointed out before, the standard sperm candle was as good as an india-rubber rule, and it seemed strange that for so many years it had continued to be used as a standard when so fallacious, and which was known to be fallacious so far back as 1868, through a series of experiments made by Mr. T. N. Kirkham, M. Inst. C.E., then the engineer of the Imperial Gas Company, in which he showed how very different one candle was from another.¹ Those experiments had lately been repeated, and he supposed from time to time they would be repeated again; but what would be the result of these repetitions he could not say. The Standards of Light Commission appointed by the Government had also endorsed the opinion, given by Mr. Kirkham and himself, that the standard candle light adopted for England was a bad one. There were other standards of light which were really standards of light, and were not such as that derived from degrees of temperature, as the Author of the Paper seemed to desire. He did not himself see what the temperature of the flame would have to do with its illuminating power, except, as Mr. Crompton had stated, with regard to the incandescent lamps. Incandescent lamps of course would give a very much higher illuminating power as the temperature was raised; and therefore in that respect, supposing one incandescent lamp were measured against another it might be useful, but as comparing the illuminating power of electricity with that of gas, or any other standard, it seemed to him that it was :

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., 440.

bad thing, and would result in erroneous statements. When there Mr. Sugg. were found differences in the illuminating power of 16-candle gas of from $1\frac{1}{2}$ to 2 candles with the best candles obtainable, it would be seen that when that was magnified up to the high illuminating power of the electric light, errors would arise which were surprising. With respect to the Tables adopted by the Author, he had introduced, as Mr. Crompton had observed, "heat-grammes," and sundry other terms unintelligible to those who did not follow very closely the line in which he had been working; but Mr. Sugg could point out that there were several standards at the present moment better adapted for the purpose of testing the electric light than the standard candle. There was first of all the gas standard introduced by Mr. Vernon-Harcourt, one which could be carried out for the purpose of estimating the standard candle accurately at any time and under any circumstances. The method that he adopted, taking a certain quantity of pentane, a product of petroleum, distilled in a certain manner, mixing a certain quantity of it with air and burning it in a proper apparatus, appeared to give a perfect idea of what a standard candle should be. That was the only one, he believed, in which the value of the light was an exact standard candle; but there were others, for example, that of Mr. Keates, in which he used spermaceti oil, and burnt it in a lamp, producing a light of 16 candles, and that light was much more easily used for the purpose of testing the electric light. He had used it himself for that purpose, and found it going for weeks without variation, so that he believed it to be a much more reliable standard than the sperm candle. The next one after that was a standard of two candles made by Mr. Methven, assistant engineer of the London Gas Company, in which he used the ordinary common gas supplied for lighting; and if there was as he said no variation in that standard when used with common gas, and Mr. Sugg believed there was a great deal of truth in what he said, it would be certainly better than the candles, and that notwithstanding there might be slight variations in it; this standard of his would be found much more suitable to the electric light. The next was a 10-candle gas standard of his own, and there were several others which were very useful; and if the electric light was to be estimated for its illuminating power, it would be better to estimate it by such a standard as these than by the fallacious standard adopted of a parliamentary sperm candle. There was one remark made by Mr. Crompton on which he would make an observation, and that was as to the manner in which testing the electric light for illuminating power could be carried out. In the

Mr. Sugg. case of gas, the assumption was that the light was given in a circle all round the burner—equal in all directions—and nearly all round in a vertical circle. It was not so with the electric light. With the electric light the light came from between the two carbon and the strongest light was in one direction; it did not light equally round the vertical circle, neither did it light equally in the horizontal circle; because on whichever side of the centre the carbon rested, one side or the other, a greater light was shown. It could be seen with a Bunsen photometer that this variation would produce very great errors. With regard to the incandescent-light that, of course, could be tested in exactly the same manner as gas except that it must be tested as a flat-flame burner; because he presumed that the light was given more strongly in the direction of the one side of the loop than it was across the loop, so that if the mean of the edge and flat of the lamp was taken a very good result would be obtained. But with the arc-light it certainly did seem necessary that a correction should be made when it was tested with a photometer horizontally or at an angle, for an evident error existed in the value of the result, caused by the fact of the light not giving its light in all directions alike, as supposed by the construction of the photometer. With the Jablochhoff light the result more nearly approached that given by a candle than in any other with the exception of the Jamin, which was the reverse of the Jablochhoff. Either of those could be easily tested in the manner he had stated; but with the arc-lights it would be necessary to make the correction, and he had not seen that that correction had ever been made.

Shoolbred. Mr. J. N. SHOOLBRED said, he wished to refer to the Tables contained in the Paper. There was a very material difference in the way they were arrived at, which the Author seemed hardly to be aware of, and which ought to be pointed out. All the lights named in the first Table were lights that had been produced and measured directly from the electric machine, or the dynamo itself. The second Table, on the other hand, represented the result of experiments carried out by Sir William Thomson upon a single Swan light, which Mr. Shoolbred was allowed to be present, and in which the Faure accumulator battery was used, the current being taken directly from that instead of from the dynamo. The results showed points of considerable interest, and, he thought, opened a very large future for incandescent-lighting where a steady current was used. Sir William Thomson not being fully satisfied with the photometric measurements, and having to leave town, allowed him to make some further experiments, and the result of the second series

experiments shown in the tables and curves annexed. The series Mr. Shool of experiments was carried out upon a single Swan light and a single Maxim light; increments of current being made by successive additions of five Faure cells at a time. The photometric measurements in the second case were carried out with the instrument to which Mr. Sugg had referred, and with Mr. Keates' 16-candle sperm-oil lamp as the standard of reference. The oil consumed was accurately weighed, and there was every reason to believe that the measurements were carried out accurately. The curves represented severally the candle-power, the measured potential, the intensity of the current, and the amount of mechanical energy in HP. This last was the simplest manner of putting the mechanical energy expended; he quite agreed with Mr. Crompton, that the Author had needlessly complicated the Paper by introducing gramme-degrees, foot-lbs., or heat-units; all of which could be deduced from the ratio generally made use of—that of candle-light per HP. The amount of mechanical energy converted into electrical energy was indeed the basis of the whole of this mode of generating electricity. In practice the condition of incandescent lights, when working direct off a dynamo-machine, and without an accumulator, was represented approximately by the

TABLE of COMPARATIVE EXPERIMENTS with FAURE ACCUMULATOR ON INCANDESCENT ELECTRIC LIGHTS.

1. SWAN INCANDESCENT LAMP in CIRCUIT.

Number of Faure Cells used.	E.M.F.	Current.	Light.		Mechanical Energy. ¹		
	Volts.	Ampères.	Standard Candles.	Becs Candel.	HP.	Kilo- grammetres.	Heat Units (Joule).
30	73	1.28	22.4	2.36	0.125	9.52	5.3
35	85	1.84	65.6	6.91	0.209	15.94	8.9
40	97	2.38	141.0	14.84	0.309	23.53	13.2
45	104	2.50	204.0	21.47	0.348	26.50	16.3

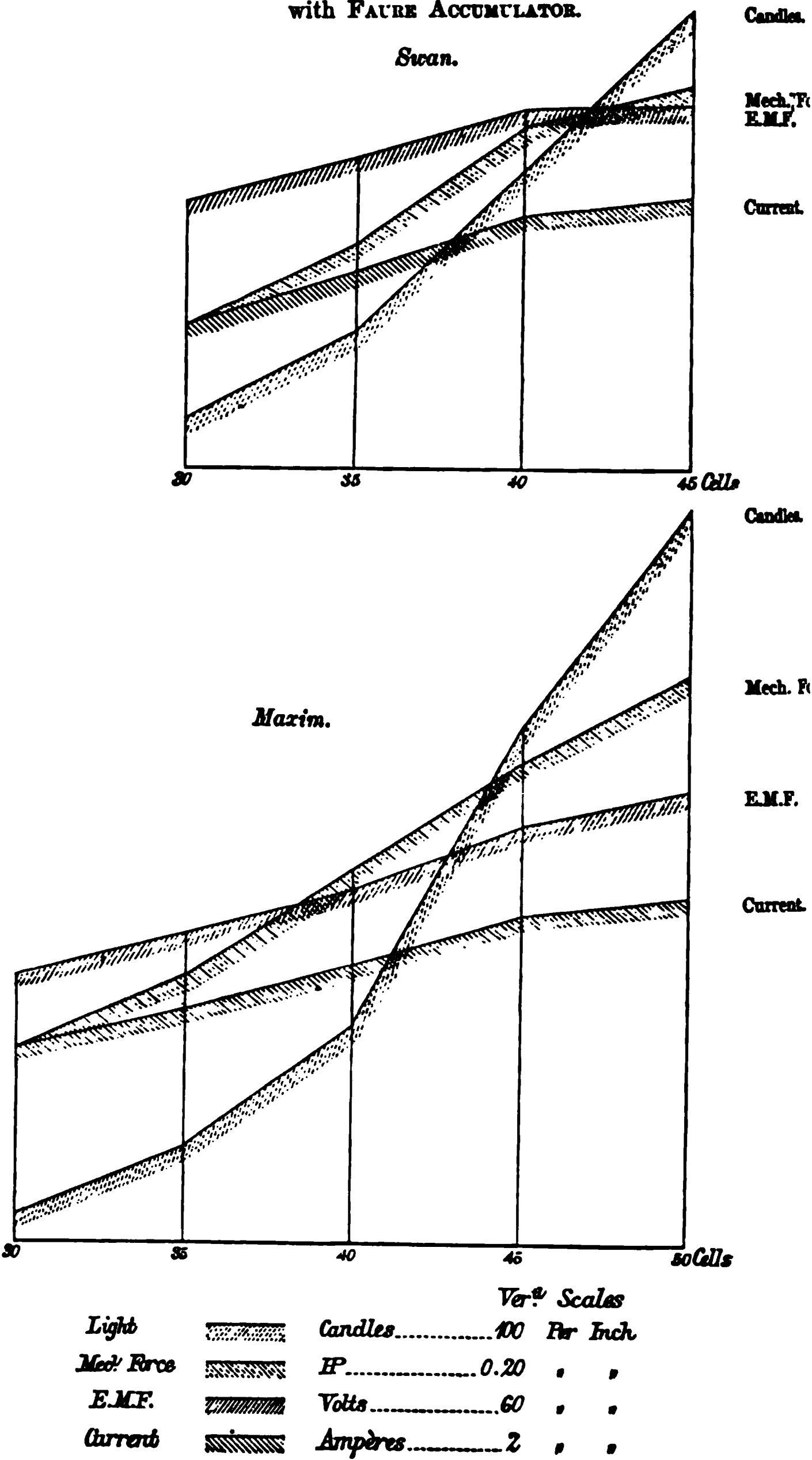
1. MAXIM INCANDESCENT LAMP in CIRCUIT.

30	74	1.81	16.0	1.68	0.179	13.65	7.6
35	85	2.24	45.3	4.77	0.255	19.41	10.9
40	98	2.59	101.1	10.64	0.340	25.87	14.5
45	113	3.00	229.0	24.11	0.454	34.56	19.4
50	124	3.20	333.0	35.05	0.531	40.45	22.6

¹ The mechanical energy lost in charging the accumulator from the dynamo is not included.

100lbred.

COMPARATIVE EXPERIMENTS IN INCANDESCENT ELECTRIC LIGHTING
with FAURE ACCUMULATOR.



diagrams (see preceding page). Such being the limit under the ordinary conditions, the value of the intervention of the accumulator was represented by the gradual progress towards the right. It would be seen how greatly the intensity of the light could be increased, and at the same time its economic value raised, in proportion to the current expended, by using the steady current of a storage accumulator. In another way the economy of these lights could be augmented; inasmuch as their life would be considerably lengthened owing to the use of the steady current. It had been mentioned, that if the incandescent-lights were urged beyond 16 candles there would be a gradual deposit of carbon on the glass, and the filament of carbon would be destroyed. He had noticed himself the phenomena referred to of the deposit of carbon, but that was owing to the improper use of the lamp; for if a lamp which was only intended for 16 candles was pushed to 25 or 30 candles, there would of course be produced an extra strain. But to say that incandescent-lights were limited by all the makers to 16 candles was totally fallacious; because they could be made of whatever candle-power was required. Just the same as a gas-burner could be made to consume 2, 3, 4, or 5 cubic feet of gas, so the resistance of the incandescent-lamp could be altered so that it would give from 10 to 40 candles or more. With regard to the proportion of candle-light given off per HP. absorbed with the incandescent-lighting, Mr. Swan had himself some two years ago limited it to from 150 to 200 candles at the outside per HP. There appeared to be a great deal of difference with regard to the cause of the large discrepancy between the proportion of light produced per HP. absorbed, with the arc over the incandescent-system; an explanation given some time ago by Mr. C. F. Varley seemed to point to the true cause. It was suggested that a much larger proportion of the current was used in warming up the carbon to incandescence than was required to pass from that stage to the production of the arc; and in this greater light-giving value of this last portion of the current might be found some explanation of the apparent discrepancy. If what was indicated by the diagrams about the use of an accumulator in conjunction with the dynamo was correct (practically the substitution of the 40-cells vertical line, in the diagrams, instead of the 30-cells one), it might be argued that incandescent-lights might, by its use, be very much more economical in their results than they had hitherto been. The fact that more duty could be got out of gas when used in a gas-engine than when used for illuminating purposes was not surprising. In the report of the Committee of the House of Commons,

Shoolbred. in 1879, On Lighting by Electricity, it was pointed out that the heat-giving properties of gas exceeded considerably the light-giving ones. Bunsen had shown that the light-giving properties were only $6\frac{1}{2}$ per cent. in 100 volumes, whereas the heat-giving properties were no less than 87 per cent.

Professor Tyndall. Professor TYNDALL remarked that he had not dealt much practically with this question of determining the candle-power of the electric light. He had, in association with Mr. Douglass, done something of the kind, but that was a long time ago. He noticed, of course, that contending parties were here upon the platform, but from those he begged to entirely abstract himself. With regard to Table I., he believed the results might have been predicted *à priori*. It must be remembered that the so-called electric light was a thing of an exceedingly composite character. It had an outflow of rays that were entirely incompetent, even when they impinged upon the retina, to excite vision. Years before the present amazing powers of the electric light were developed, he had experimented upon the light produced by a battery of fifty Grove cells, which evoked what in those days might be called a very powerful electric light, and found the invisible radiation, meaning by that the radiation which was incompetent to excite vision, to be 90 per cent. of the whole. He was afraid it was impossible to get rid of this condition. This invisible radiation appeared to be, so to say, the substratum of the visible. The luminous rays must be built, as it were, upon the non-luminous rays. The same was the case with the sun itself, as Herschel was the first to prove. Müller found that the luminous rays of the sun were only one-third of the total emission by the sun; that the invisible, obscure, calorific rays emitted by the sun were two-thirds of the total radiation. In the case of the electric light the invisible rays were by one series of experiments proved by himself to be 7·7 times the visible; and in another series of experiments, made according to a totally different method, the invisible calorific rays proved to be 8 times the visible. With regard to the sun, as he had said, its invisible radiation was twice as great as its visible radiation; but higher in the atmosphere, above the screen of aqueous vapour that overspread the earth, if a spectrum of the sun was obtained, it would be found that then the obscure radiation of the sun approximated to that of the electric light. He had received a letter some time since from a gentleman who had been experimenting at a height of 12,000 feet above the sea, in a very dry region of the earth in the Sierra Nevada Mountains in California, and he declared

that there was an enormous extension of the invisible spectrum of the sun in those regions. Probably at the limit of the atmosphere the invisible radiation of the sun would represent six times the energy of the visible radiation. With regard to the Table, the Author of the Paper took into account the total amount of power absorbed, and the question was, how much of that power was converted into luminous rays, into those rays that were effectual for vision, and how much into rays that were not effectual for vision. On theoretical grounds he should have inferred that the Table must be as the Author had stated, and that, as Mr. Crompton had remarked, the more intense the power was made by the introduction of a resisting interval between the two carbons of the arc, and the higher the electromotive force invoked to urge the electric current across the interval, the greater was the proportion of the luminous rays introduced into the total radiation. In the first lamps mentioned, the number of foot-lbs. per candle-power was very small compared with the smaller lights. This simply expressed, in the case of the Werdermann and in the case of the incandescent-light, that the energy was in great part expended in the production of invisible heat-rays, and that in the intense arc-lights a greater fractional part of the total energy was converted into wave-motion competent to excite vision. Professor Tyndall.

Mr. W. ATKINSON did not know whether the Author had stated at what distance the experiments had been made with the light. He understood that there was great difficulty in arriving at any conclusion as to the power of the electric light, dependent upon the different distances at which the experiments had been tried. He believed it had been discovered that, even in comparatively very short distances, in a room within the space of a few feet, very varying results would be obtained. The rays of the electric light were probably readily absorbed by the atmosphere when humid, as Dr. Tyndall had mentioned, in the case of the sun. Then with regard to the economy or the cost of gas, the element of the destruction of fittings in a house had not been referred to. If the electric light and the gas light were compared, it was clear that, to a consumer, the electric light would be more economical, because there would be no destruction and no dirt. Mr. Atkinson.

Mr. J. N. DOUGLASS said his experience with the electric light had been entirely with arc-lamps. It was a pity that the comparison in the Paper as to the cost of gas and of the electric light, had not been made with gas in London instead of in New York, because the cost of gas in New York was about \$2½ per 1,000 cubic feet, while in London it was about 3s. Following the figures Mr. Douglass.

glass. of the Author, he found he had given a 4-light chandelier of 64-candle power, as costing per hour in New York 20 cents for gas, the burners being of the efficiency of the London standard burner. A burner would give about 5 candles per cubic foot of gas consumed; therefore, the above result would be got in London at the cost of about 1·8 per hour, as against 8d. per hour in New York. As Mr. Jones had pointed out, the only cost given in the Paper for the electric light was that of the motive power, and that was stated to be 4·1 cents, being more than twice the cost of the gas-light in London. There appeared here the same difficulty of comparison that was met with in lighthouse illumination; and, from his experience, he might say that if the electric light could be fairly compared with oil or gas as consumed in lighthouses, it would be found that, with the arc-light about ten times the amount of light per unit of cost was obtained with electricity above that of gas. Unfortunately, the element of cost of plant and of additional cost of labour came into play; and up to a certain intensity, at a lighthouse, oil was the cheapest light. But then an intensity could be attained ten times that of the oil with the electric light; and there would be about five times the amount of light per unit of annual cost than with the oil; however, the first cost and annual maintenance were doubled. If that first cost could only be reduced to that of the oil or the gas-light, electricity would, no doubt, prevail. With regard to the measurement of candle-power, there appeared to be difficulties with the electrical mode of measurement; and he, for one, would not be disposed to accept any apparatus for electric light, unless he measured the light photometrically in addition to the system proposed by the Author of the Paper, because, as pointed out by Mr. Crompton, there was the quality of the carbon coming into play, which was liable to considerable variation. It was quite possible in the same bundle of carbons to get differences of quality of certainly 50 per cent. With regard to the candle-power, he saw no difficulty in using an ordinary candle with care. Any one who was used to it could arrive at results, certainly within 5 per cent.; and to measure the electric light, which varied within an hour 50 per cent., surely the candle was near enough a unit of comparison. The great difficulty with the candle was the difference in colour. That was, however, easily got over if we were wished to reduce the actual candle-measurement to the intensity at the actual candle-flame colour by colouring the electric light with yellow glass, and bringing it to the colour of the candle.

SIR WILLIAM ARMSTRONG, President, said he had had considerable experience with the incandescent system of lighting. He had used it at his house in the country for nearly a year. He had gone through many troubles and difficulties, such as early experimenters always had to encounter; but, upon the whole, he could decidedly say that his experience had been satisfactory. No doubt the comparison of candle-power between the different systems of lighting was a very important matter; but it was by no means the only consideration that presented itself. He commenced with attempts to make the 'arc-light available for domestic use; and after trying various systems and various arrangements, he came to the conclusion that no possible improvement that could reasonably be hoped for would make it suitable or desirable for domestic purposes. He then tried Mr. Swan's system, and with the lamps which he furnished in the first instance, and which were made very carefully, no doubt, by hand, the endurance and illuminating power were exceedingly satisfactory. He came to the conclusion that each single lamp gave about as much light as an ordinary duplex kerosene lamp, usually estimated at about 25 candles. When the company commenced their operations, they changed the system, and instead of using single lamps, they used two lamps in series—at least they recommended the employment of two in series, instead of one in parallel. Owing, perhaps, to imperfect experience, he found the durability of the new lamps much less than that of the first lamps supplied; but after a good deal of disappointment and change he eventually obtained lamps which, in pairs, fairly represent what the single lamps did before. It was premature to attempt any comparisons either as to the illuminating power or cost of renewals, for it was quite clear that the whole system was yet in its infancy. He could state from his own experience that there was the widest possible difference between the lamps supplied. He had some lamps at the present time which had been in use from the very first, whereas he had also had some that failed after a few hours' use; therefore, until the manufacture settled down to something mature, and the difficulties of starting were fairly got over, there could hardly be judgment as to the capabilities of the lamps, either with reference to endurance or illuminating power. This much he could say, that no deficiency of candle-power or endurance such as had been attributed to them would induce him to abandon the system. Gas was an admirable means of lighting in its proper place, but in private rooms it was undoubtedly very objectionable. The incandescent-light had no connection whatever with the

Sir William
Armstrong.

William atmosphere, and therefore had no contaminating effect upon it; it had very little heating effect; it was perfect in colour, perfect in steadiness, and in fact was the perfection of lighting for domestic purposes. That, at least, was his experience; and he had no doubt that difficulties which had arisen, and were arising, would be got over, and that the incandescent lamp would attain to a perfectly satisfactory state. The number of lights in his house was sixty, that was thirty pairs. He had more, but could work that number at the same time. The source of power was a turbine situated nearly a mile off; and with 7 HP. he was enabled to maintain those sixty lights. Most of the lamps that had failed had not failed through the actual wearing out of the carbons so much as from defects in their manufacture, from points at which there seemed to be some defect which made them liable to give way in use. He felt, however, sure that, when the manufacture of the carbons was perfected, all difficulties of that kind would be got over. The light in his case, using water-power, was highly economical. There was the cost of the labourer's attendance upon the machine at night to supply the sixty lights, and the only other expense was the cost of renewals, which would certainly not be very serious, according to his past experience. One point he might mention was the extreme importance of having an absolute uniformity of motion in the generator. The smallest variation immediately produced a disagreeable twinkle upon the lights; and so sensitive were they, that while he used belts made in the ordinary way with joints he could count the revolutions of the wheel; that was to say, every time a joint ran over the pulley it made a sufficient variation to cause a slight effect on the light. He could not obtain an absolute uniformity until he used an endless belt made like a flat chain of leather links stamped out of the sheet, and joined together by putting a pin through, a form of belt now pretty generally used in cases where very even and regular motion was required. He was afraid that unless the gas-engine was supplemented by means to obtain a very steady and uniform motion, the absolute steadiness of light which he had attained would hardly be obtained from it; but no doubt there were means, when attention was directed to the attainment of that particular object, which would be found to remedy any inequality.

Higgs. Dr. Higgs remarked in reply, through the Secretary, that the results given in the Paper were intended partly to be intercomparative, and partly were an endeavour to reduce the observations of different authorities to a common standard. This common

standard he assumed to be represented by the "energy" absorbed in the light-centre. He did not suppose that "temperature" and light were related; but that if light were any form of energy, then that light would be related to the energy of the light-centre; he had measured this energy in heat-units and not in "foot-lbs. per candle-power" as suggested, because he did not know what a candle-power was, in which ignorance it seemed he did not, judging from the remarks of those who had favoured him with their criticism, stand alone, and he thought he did know what a heat-unit was. Between the energy as measured in heat-units, not the temperature, he had found the relation to be, as stated. But besides criticism, he had thought to elicit facts and measurements from others.

Correspondence.

Mr. K. W. HEDGES observed that the Author, in referring to the way in which he measured the electric light in comparison with the method adopted by Sir W. Thomson and Mr. Bottomley, did not mention what that method was. The great difficulty with powerful electric lights seemed to be the variation of their colour as compared with the present standards, the sperm candle and carcel burner. He thought that, failing a better standard, the difficulty might be obviated by photography, either as adopted by Captain Abney by photographing the spectrum, or in a simpler manner by photographing the luminous crater in the positive carbon. The intensity of the light was greatest at the latter point, and by interposing glass of known opacity between the light and the sensitive plate, and noting the time taken to produce a photographic image, the comparative amount of light from any two sources might be ascertained. He noticed the Author's opinion that incandescent-lighting was theoretically six times the cost of arc-lighting. This would make the incandescent-light as dear or dearer than gas, and might deter the introduction of the electric light into theatres and crowded rooms where it was much needed. The cost of arc-lighting was considerably less than that of gas, the only drawback being the colour which did not harmonize with gas. He thought the difficulty might be got over by enclosing the arc-lights in coloured globes so as to tone the light to the colour of gas. From an experiment in one of the picture galleries at the South Kensington Museum, he found the loss of light to be less with a suitably coloured globe than with an opal one. If two

Mr. Hedges. or more arc-lights were enclosed in a lantern, the fluctuation of any one would be less noticeable, and one could be turned on or off as necessary. With a margin of six to one in favour of such a lantern, which could not be at once detected by the uninitiated as coming from an electric source, and which had all the advantages possessed by incandescent-lights, the saving in cost would alone cause arc-light to be preferred to the latter.

Mr. Ward. Mr. RADCLIFFE WARD observed that if the subject had been discussed on the cost of the electric light as against gas, he had no doubt that several engineers would have been prepared to prove that, even on the very restricted scale of electric light-installations now existing, gas could be competed with. He would first direct attention to the passage in the Paper, wherein it was stated that a Serrin Lamp and Gramme Machine gave a light of 3,600 candle-power when the arc-resistance was about $1\frac{1}{4}$ ohm.; and that with the same arc-resistance a Crompton lamp yielded a light of 24 candle-power; also in the case of the Gramme and Serrin Lamp the current or amperè current was stated to be 45·7; in the case of the Crompton lamp only 24. This, according to his experience with good carbons, was what frequently gave 3,600 candles as "diffuse beam;" such an extraordinary difference between the Crompton and Serrin Lamp as 24 to 45·7, required some explanation. The author put such figures in the Paper, without comment, was misleading and puzzling to any one not a practical electrical engineer. It was not stated what were the machines used, that was, of what type? He should be particularly interested to know what class of Gramme machine was used. The Author did not appear to take much of the carbon element, whereas Mr. Ward agreed entirely with Mr. Crompton, that the carbon question was most influential and important, not only in arc but also in incandescent-lighting. According to his experience, and indeed the point was self-evident and could be easily foreseen, one of the most important features in the construction of incandescent-lamps was the form of the carbon filament regarded as a structure; the chief point being the proportion of radiating surface to the total mass, and the cross-sectional area. He thought, in using the electric light for domestic purposes, it would be advisable to employ a dynamo-machine directly in the day to "charge" accumulators placed in some convenient position in the house, and then work off the accumulators at night direct to the lamps. This method would be preferable on account of being able to work in a house with a lower electromotive force. With respect to the comparative cost of the electric light, he would not go into details; but the cost of lighting Whitehall

now practised by gas, was considerably more than if it were lighted Mr. Ward
by an electrical system, such as could advantageously be employed.
Finally, he would suggest that the cost of lighting lighthouse
lnterns by electricity might, in the not distant future, be much
reduced by obtaining the current from a large central electric
generating station in the neighbourhood; say the South Foreland
lights from the "Dover Town electric generating station" that was
to be.

14 February, 1882.

Sir FREDERICK J. BRAMWELL, F.R.S., Vice-President,
in the Chair.

(*Paper No. 1845.*)

“Air Refrigerating Machinery and its Applications.”

By JOSEPH JAMES COLEMAN, F.I.C., F.C.S., Assoc. Institution
of Engineers and Shipbuilders of Scotland.

A PAPER on the mechanical production of cold, by Mr. Alex. Carnegie Kirk, M. Inst. C.E., was read to this Institution in January, 1874.¹ Although Mr. Kirk's Paper was confined to the description of a new and ingenious method of cooling brine or other liquids by the alternate compression and expansion of a confined volume of air, the discussion embraced the consideration of the cooling of liquids and the making of ice by chemical methods.

Since that time great progress has been made with a special department of mechanical refrigeration, namely, the cooling of the air of buildings and of ships, with the development of which the Author has been closely identified.

It will be convenient, however, to glance at certain general principles regulating artificial refrigeration before specially dealing with the subject of cold-air machines. All liquids, when in the state of vapour at temperatures much above their boiling point, behave as permanent gases—atmospheric air being in fact the vapour of a liquid, one of its constituents, oxygen gas, boiling at about 200° below zero Fahrenheit,² and under a pressure of 2 tons per square inch, according to the recent researches of M. Raoul Pictet.

The general law regulating the employment of these vapours in artificial refrigeration is expressed by the formula

$$\frac{P \times V}{T} = \text{a constant for each vapour,}^3$$

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 244.

² “Chem. News,” vol. xxxvi., p. 281. 1876.

³ *Vide* “Theory of Heat.” By J. Clerk Maxwell, p. 179. 1880.

in which P represents the pressure, V the volume, and T the absolute temperature.

Thus, if a certain space contains a cubic foot of air, and into the same space another cubic foot of air is forced by a pump, the absolute temperature will be raised; if, on the other hand, a similar-sized space containing a cubic foot of air has the pressure of its air reduced to one-half by an exhaust pump, its absolute temperature will be lowered. In either case mechanical energy requires to be expended in order to produce the thermometric change, in the first case in overcoming the elasticity of the air, in the second case by the elasticity of the air exerting force against the piston of the pump while displacing the atmosphere.

Together with this general law is another common law of thermodynamics equally regulating the performance of all machines for artificial refrigeration expressed by the formula

$$E = C \frac{T - T_1}{T},$$

in which C represents the cooling effect desired, T the absolute temperature of the hot end of the machine, and T_1 the absolute minimum temperature of the cold end of the machine, and E the energy required to produce the effect, which may be in thermal units developed by consumption of coal for an ammonia machine, or in foot-lbs. of energy expended in compression by a cold-air machine.

The explanation of this formula is:—Supposing it be required to cool a quantity of brine 160° , and next to cool sixteen times that quantity by 10° , if in each case the absolute initial temperature is 500° Fahr., then by this formula the energy required to produce the result in the first case would be about 44 per cent. more than that required in the second case. This formula is also not affected by the phenomena which attend the liquefaction and subsequent vaporization of condensable vapours, because the heat-changes peculiar to the condensation are repeated in an inverse order when the liquid evaporates, and compensate each other. It therefore follows from these considerations that by far the most economic results, as regards coal consumption, will be obtained when machines are worked within a small range of temperature, as in breweries, where water has frequently to be lowered only 10° . This is one of the reasons why ether, ammonia, and sulphurous anhydride machines frequently show such favourable results when compared with cold-air machines, in which latter the range of cooling required by the user of the machine is frequently much more extensive.

Any machine which is worked through the medium of a readily condensable vapour, such as ammonia, ether, methylic ether, or sulphurous acid, has its action limited by the boiling point of the volatile liquid; it is therefore impossible with such machines to get so large a range of cooling in one operation as can be accomplished by air. The low temperatures which Pictet required for the liquefaction of oxygen and hydrogen were obtained in stages, first by ebullition of liquid sulphurous anhydride in vacuo producing sufficient cold to liquefy carbonic acid gas at a pressure of four atmospheres, and then in taking advantage of the still greater cold produced by the ebullition of the liquid carbonic acid gas in vacuo. There is, however, no reason to suppose that the same or much lower temperatures could not be obtained by the compression and expansion of air in a single operation.

The boiling point of ether under ordinary atmospheric pressure is 95° Fahrenheit, so that in order to use it as a medium for refrigeration it requires to be evaporated in vacuo—that is, pumping is needed, which causes it to boil rapidly, and it becomes cooled as the vacuum is increased; but the cooler it becomes the more slowly it evaporates, until, when its temperature sinks to a little below zero, evaporation ceases altogether, although the pump may be maintaining the vacuum. It follows from this that if the brine, which is usually the medium being cooled, returns back to the boiling ether without having picked up heat from the substance being cooled, the action is gradually diminishing. This phenomenon is very likely to occur when the brine cooled by such a machine is circulated in pipes through a chamber containing atmospheric air, more or less saturated with aqueous vapour, and as would actually be the case with a chamber containing fresh meat being cooled. The brine pipes under such circumstances become externally cooled with a non-conducting covering of ice, having the appearance of enamel, which, unless removed, accumulates to the extent of several inches in thickness, thus interfering with the transfer of heat, and practically preventing the room from being reduced to a lower temperature than the freezing point of water, or the melting point of the exterior surface of the crust which surrounds the pipes, whilst the brine is liable to be returned back to the evaporating ether at much lower temperatures than it should for the economical working of the machine. The same remarks apply to the employment of sulphurous anhydride and of ammonia, the limiting action in the case of ammonia, which is considered the most effective in practice, being about 35° below zero of Fahrenheit when it is employed at atmospheric tension, as

in Carré's process, or in Rooce's process, though of course much lower when evaporating into a vacuum, as in Professor Lindé's machine.

Almost all the statements as to the performances of these machines refer to their employment under favourable conditions, namely, the cooling of water or other fluids, or the making of ice, in which the temperature of the saline solution, or glycerine transferring the heat, never need sink below 20° Fahrenheit. When they come to be employed for cooling solids, such as masses of meat, weighing 2 or 3 cwts., to temperatures below freezing point, great practical difficulties occur in the transfer of the heat through the non-conducting air in which the meat is suspended to the pipes containing the brine, unless such pipes or other equivalent circulating apparatus are brought into close proximity to the solid masses. On board ship such arrangements are almost impossible if the ship's hold has to be employed for general cargo on the outward voyage, and in any case networks of such circulating apparatus are inconvenient and liable to leakage and to injure the cargo.

From these considerations, even if the use of dangerous chemicals on board steamers were allowable, it is apparent that cold-air machines, in which air is first compressed and then expanded, are the most convenient form of refrigerating apparatus for use at sea; and it is also evident that they are the most convenient form of machine for cooling the air of apartments generally. The great enemy of cold-air machines is friction encountered in the working of the machinery, particularly that which results in the development of heat in the expansion cylinder itself. This point will become clearer in the remarks which are to follow.

In regard to the prime cost of machinery, not much difference exists for a given amount of cooling power whichever system of refrigeration is adopted.

Although Sir John Herschel and others had directed attention previously to the desirability of utilizing the expansion of compressed air for the production of cold, the credit of actually constructing such apparatus appears to belong in this country to Professor Piazzi Smyth, and in America to Dr. Gorrie. As early as 1839, Piazzi Smyth had commenced small experiments, and afterwards visited a large ironworks near Edinburgh, and placed a thermometer in the diverging cone of air escaping from an orifice, 1 inch in diameter, made in a large reservoir containing air compressed to the extent of about one quarter of an atmosphere, and found the escaping air to be 29° Fahrenheit colder than it

was before expansion. Professor Smyth seems to have worked for a long time with apparatus on the method of blowing air through loaded valves, before the principles of the mechanical theory of heat as applied to gases were properly understood. The experimental demonstration of this theory was made by Dr. Joule in 1845, in two sets of classical experiments, and subsequently by Dr. Joule and Sir W. Thomson, M. Inst. C.E., in a third series of such experiments.

In the first series of experiments,¹ Dr. Joule proved that the mean temperature of compressed air of a density of 22 atmospheres was not altered by being expanded into an empty reservoir of a similar size to that containing the compressed air—thus confirming the law stated at the commencement of this Paper, that no change of temperature occurs by the mere expansion of a gas without performance of external work, such as can be developed by letting the gas expand behind a piston. In the second series of experiments, a metallic reservoir full of compressed air was allowed to expand into the atmosphere, and it was found that the reservoir became cold in exact proportion to the force exerted by the escaping air in displacing the atmosphere. In the third series of experiments made by Dr. Joule and Sir W. Thomson conjointly, it was proved that when compressed air was expanded through small orifices into the atmosphere, the cold developed by the force exerted in displacing the atmosphere was almost entirely counterbalanced by the various frictions encountered by the molecules of air before coming to rest after expansion.

From this it follows that no satisfactory apparatus can be devised by simply allowing compressed air to expand behind a loaded valve—a fact which the Author has recently demonstrated.

In Fig. 1 is represented a ground plan of the refrigerating machinery recently erected by the Bell-Coleman Mechanical Refrigeration Company, on board the Cunard ss. "Servia." The air is compressed in the air-pump P by the steam-cylinder A, and the compressed air, cooled to the temperature of the water available for cooling, is then brought to the expansion-cylinder E, where it is expanded in the act of doing work transmitted to the same shaft to which the pump and steam-piston rod are attached. Under such circumstances, the air, when discharged into the blast-box D, is about 100° colder than immediately before expansion, when the amount of compression of the air is about 30 lbs. to the square inch above the atmosphere. The experiment was

¹ *Vide* Phil. Mag. vol. xxvi., 3rd Series, May 1845, pp. 369–383.

made in this way: instead of allowing the air as usual to expand behind the working piston E, the piston-block was taken off, so that the expanding air could blow through the cylinder, without doing work, into the blast-box D, and it was found that when the air-pressure was regulated by a throttle-valve V, no lowering of the temperature of the air in the blast-box could be detected, when at exactly similar air-pressures, but with the expansion taking place in the act of doing work propelling the piston, 60° reduction of temperature occurred. The air-pressure at which the experiment could be made was less than the normal working pressure of the machine, owing to the crank-shaft being deprived of the assistance of the expansion cylinder.

Professor Rankine, in a paper communicated to the British Association in 1852, calculated that 25,000 cubic feet of air should be cooled per hour from 90° to 60° by an engine of 1 HP., allowing for friction as in a Cornish engine; but he advocated avoiding friction as much as possible, by effecting the compression of the air by a bell-shaped gas-holder being depressed into a reservoir of water, and expanding it back again to its initial pressure in a similar shaped vessel attached to the opposite end of an oscillating beam, by which means, he said, 66,000 cubic feet should be reduced 30° Fahrenheit by 1 HP. per hour. In the same year, Sir William Thomson went independently into the subject, and specified the size of compression cylinder and of expansion cylinder, which are theoretically required to cool 1 lb. of air per second (15.5 cubic feet), from 80° to 50° Fahrenheit, and also the power required to do this amount of work, which he specified to be 0.288 HP., supposing there to be no loss of effect from friction. This, it will be observed, is equivalent to 193,750 cubic feet per hour, reduced 30° Fahrenheit by 1 HP. per hour. Sir William Thomson also pointed out in the same Paper an arrangement which would be equally suitable for heating buildings, proposing that air should first be rarefied so as to be cooled a little, and then passed through tubes surrounded with a current of cold water (say from the town supply), and from which the slightly rarefied air could pick up heat, and being restored to atmospheric pressure, would be to a corresponding extent warmed. By this process it is possible to warm air through a range of 30° with one-third of the coal which would be required by using it directly, if all the heat escaping in any way from the engine or from the fire be added to that which is picked up by the tubes surrounded by water. Sir William Thomson has also remarked recently that this may be the future of heating buildings, when such sources of energy are

available as that of the Falls of Niagara, for working the machines, and is quite as likely to be satisfactorily solved as has been the reverse operation of cooling.

A practical and theoretical discussion of the subject was undertaken by Professors Rankine and Piazzzi Smyth jointly, and lasted from 1851 to 1856, being chiefly with reference to the cooling of buildings in India, and for a particular military hospital—the idea of Professor Piazzzi Smyth being to employ hand or animal power for the work. The investigation effectually demonstrated that the cold produced by the compression and subsequent expansion of air, unless carried to higher pressure than can be attained by the mere depression of a bell-gasometer into a tank of water, is useless for practical purposes, as in order to get a compression of one atmosphere, such tank would have to be 34 feet high. It was found that though this suggestion of reducing friction, which is the great enemy of cold-air machines, to a minimum was effectual, there was another enemy, viz., the influence of the heat evolved by the condensation of the aqueous vapour, owing to the air being reduced in temperature. Thus 20,000 cubic feet of saturated air at 90° Fahrenheit contains 47 lbs. of water, but only 17 lbs. at 60°, so that the latent heat liberated by the condensation of the water, even although the air is not perfectly humid, entirely neutralises the effect of the compression to a fraction of the atmosphere.

The question of cooling buildings and hospitals in India remains much as it was left in 1856, but as more experience has now been gained of a practical character in the working of such machinery, it is to be hoped that its importance to the health and comfort of the Queen's subjects in India, and other tropical countries, will not be overlooked.

Dr. Gorrie's machine was not a cold-air machine in the sense that the word is now used—that is, a machine for cooling air and then delivering it into apartments for the purpose of ventilating and cooling them—it was a machine for cooling brine or some other liquid which would not freeze easily, and which in its turn could be used in making ice. According to information supplied to the Author by Mr. James Brownlee, late of New Orleans and now of Glasgow, the first machine was constructed in New Orleans before the year 1845, and consisted of a cylinder about 8 or 9 inches in diameter for compressing air, and of another cylinder about two-thirds the capacity of the first, in which the air was expanded. A jet of water was injected into the compressing cylinder, and the compressed air was discharged into a vessel surrounded by cold water, where it was further cooled, and the injected water allowed to settle. The

air was then admitted to the expansion cylinder, and whilst expanding a jet of salt water was injected. The salt water being drawn off, was allowed to circulate around vessels containing fresh water to be frozen. In the year 1850, a patent was taken out in Great Britain by Mr. Newton, the patent agent (communicated from America), the process being identical with the one just described. Dr. Gorrie died shortly after the appearance of this patent, which does not seem to have been reduced into successful practice.

In the year 1857, Dr. C. W. Siemens obtained provisional protection for an invention which was not completed; it consisted in combining with an arrangement somewhat similar to that of Dr. Gorrie's, an "interchanger" for the purpose of subjecting the compressed air before expansion to the waste cold air travelling back to the pump to be re-compressed with a view to economise cold, but no method was specified for removing the moisture which such an arrangement would cause to be deposited from the condensation of the aqueous vapour in the air, nor does it appear that the patent was ever completed or put into practice.

In 1862 appeared Mr. Kirk's machine, already described to this Institution, and which was also a machine designed for cooling liquids or making ice; and the details of which, as also those of the remarkable preliminary experiments, in which mercury was frozen, are as interesting as the practical success of his machine was marked.

In 1869 two German engineers, Messrs. Windhausen of Brunswick and Nehrlich of Frankfort-on-the-Main, took up the matter of cold-air machines with great vigour, re-patenting a great deal that was old in almost every country in Europe, followed by Mr. Paul Giffard, in 1873. Windhausen's patent of 1869 directed the compressed air to be cooled in pipes surrounded by cold water. Giffard's of 1873 directs it to be cooled by injecting water into the pump. Windhausen having tried surface cooling, reverted to water injection into the pump in a patent of 1873. Nehrlich, in 1874, went back to surface cooling. Giffard adopted direct injection in 1875, and then returned to surface cooling in 1877. The fact is that, whichever method was adopted, the discharged air was always loaded with snow to an inconvenient extent.

The reports¹ of Dr. A. W. Hoffman in connection with the Vienna Exhibition of 1873, together with the documents submitted to the jurors of that exhibition, stated that a large Windhausen

¹ *Vide* Berichte über die Entwicklung der chemischen Industrie während des letzten Jahrzehnts.

machine, capable of discharging 150,000 cubic feet of air per hour, was being made for New Orleans, and one of about 80,000 cubic feet per hour for the brewery of Mr. Peter Overbeck, of Dortmund, and one of 80,000 cubic feet per hour for the brewery of Messrs. Hildebrand, of Pfungstadt.

In regard to the first mentioned machine, Dr. Hoffman's report states that it was tried in Berlin before being sent out to New Orleans, and although the compressed atmospheric air was cooled in pipes surrounded by cold water, and not by direct injection of water, it was found that when the air passed into the expansion cylinder, the greater part of its existing vapour was deposited as snow, which interfered with the working of the machine, and choked up the escape pipes. On arrival in New Orleans it worked badly, and was dismantled. This was also the fate of the machine put up at Overbeck's brewery; but that at Hildebrand's brewery is still in occasional use, being worked off an engine used for other purposes. A few other Windhausen machines are in existence: for instance, one in Fairbank's lard refinery, in Chicago, which, the Author has been informed, has never been entirely satisfactory, and has been frequently altered. It can only be worked at low pressures, and at present it yields air at about 14° Fahrenheit, and has a compressor of 42 inches diameter and 36 inches length of stroke, and an expansion cylinder of 36 inches diameter and 36 inches length of stroke.

Latterly Windhausen has turned his attention to refrigeration by the rarefaction of air in contact with sulphuric acid.

Matters were in this position in the beginning of 1877, when the attention of the Author was directed to the subject by Sir W. Thomson, who had been consulted by Messrs. Henry and James Bell, of Glasgow, as to the possibility of constructing machinery to supersede the use of ice in the preservation of fresh meat during its passage across the Atlantic.

A small experimental machine of the Giffard type, since discarded, and resembling in appearance a little vertical donkey pump, was in existence at the works of Messrs. Hick, Hargreaves and Co., Bolton; but a review of the hundred or so previous patents on the subject, of the practical failures of the German engineers, and of the fact that no cold-air machine had got into regular use on land, not to speak of making one suitable for ships' use, was anything but encouraging.

An attentive consideration of the matter upon general principles led to the following conclusions:—

1. That atmospheric air is really not air alone, but a mixture

of aqueous vapour and air, and that when such mixture is compressed into pipes surrounded externally by water of the same temperature as the air before compression, the invisible vapour of the air becomes condensed in the direct ratio of the compression, in virtue of the law of physics demonstrated by Dalton, and expressed by the statement that a cubic foot of air in contact with water contains exactly the same weight of vapour, whatever may be the density of the air. If the density is increased, the vapour liquefies—if it is diminished, water evaporates into the air.

2. Compressed atmospheric air of usual humidity is not therefore made wetter by injection of water, provided the surplus water is run off continuously by automatic traps, air being actually dried by compressing it in contact with water, removing the water and expanding it.

3. Direct injection is the quickest and most effective method of cooling air to the temperature of the water, which is a condition necessary to the working of a machine with the least expenditure of power.

4. Injection of a shower of water into freshly compressed air tends to settle the fog caused by the sudden condensation of the invisible atmospheric vapour, thus facilitating its removal by traps.

5. That whilst the direct injection of water is desirable for cooling the air to the temperature of the water, it is not absolutely essential, if the compressed air be passed through a sufficient number of pipes surrounded by cooling water, the ultimate result in either case being that the compressed air can only be reduced to the temperature of the water, which is not sufficient to liquefy the vapour usually contained in the air, except the air pressures employed be excessively high—which is fatal, according to the first principles of thermodynamics, for working a machine economically.

6. That every lb. of vapour unnecessarily condensed liberates as much heat as will raise about four thousand times its weight of air 1° Fahrenheit, and that air absolutely dry is a condition that would abstract the fluids of animal tissue, and indeed is a phenomenon unknown in nature, the degree of humidity being generally over 50° , even in what is, in common parlance, called "dry air."

7. That a convenient way of liquefying such vapour is to apply a portion of the cold air produced by the machine to the external surface of the pipes or other vessels conveying the compressed air already cooled by water to the cylinder in which it is to be

expanded—the liquid condensed in this way being removed by automatic traps.¹

¹ Extract from Paper by the Author on the "Removal of Aqueous Vapour from the Atmosphere," read to the Glasgow Philosophical Society, March, 1881. "With a view to consider for a moment the joint effect of cold and pressure upon aqueous vapour, I have now to remind you of a well-known law of physics, viz., that when saturated vapour is subjected to pressure it will liquefy in the direct ratio of the pressure, temperature being constant; and also that atmospheric air saturated with aqueous vapour behaves in this respect just the same as if the air were not present. This principle was illustrated by Dalton, who introduced volatile liquids into the Torricellian vacuum of a barometer tube, and showed that the liquids evaporated or recondensed in proportion to the elevation or lowering of the tube in a mercurial trough. Assume, then, that air at 60° Fahrenheit and saturated with moisture is compressed to 20 atmospheres, and in a surface condenser consisting of a suitable system of tubes surrounded by an ample supply of water at the initial temperature of the air, then nineteen-twentieths of the weight of that aqueous vapour should be deposited as dew in the inside of the pipes. If the volume of the air at starting were 1 cubic foot at 60°, then it would contain 5·8 grs. of water, and when compressed to 20 atmospheres without change of temperature 5·5 grs. would be deposited, and being expanded again to its original volume and pressure, out of contact with the deposited water, it would be found to contain only 0·3 gr. of water.

"Going a step further, let us suppose that the same cubic foot of vapour saturated air at 60° is compressed into one-twentieth its bulk in another way, viz., in direct contact with water, say, by forcing it into a strong reservoir partially filled with water. Imagine the compressed air and water to be shaken together, and then allowed to stand until perfectly quiescent, the temperature being kept at 60°; now let the water be carefully drained away or detached from the compressed air, and the air be expanded to its former bulk, and it will be found to be drier than it was at the start, as it will have lost nineteen-twentieths of its vapour just as in the former case. Thus we are brought face to face with a curious paradox—that it is possible to dry air by wetting it."

	Glacier's Tables above zero. Fahrenheit.									
Temperatures . .	100	90	80	70	60	50	40	30	20	10
Weight of 1 cubic foot of saturated vapour in grains . . .	19·84	14·85	10·98	8·01	5·77	4·10	2·86	1·97	1·30	0·84
Percentage of weight deposited for fall of 10° in temperature	25	26	27	28	29	30	31	34	35	34·5

	Calculated at and below zero. Fahrenheit.												
Temperatures . .	0	10	20	30	40	50	60	70	80	90	100	110	120
Weight of 1 cubic foot of saturated vapour in grains . . .	·55	·36	·23	·14	·08	·05	·03	·017	·009	·005	·003	·0015	·001
Percentage of weight deposited for fall of 10° in temperature	35	36	37	38	39	40	41	42	43	44	45	46	47

The last principle does not seem to have been applied in practice in this country prior to the Author adopting it in conjunction with Messrs. Bell. It is true that an "interchanger" was suggested by Dr. Siemens in his incompleted patent of 1857, in Messrs. Laidlaw and Robertson's patent of 1864, and in Mr. Windhausen's of 1869, for intensifying the cooling power of the machinery, by the utilisation of the waste cold, after air has been used for freezing water; but in reality there is no waste cold air if rooms of graduated temperature are being cooled; neither would a simple heat exchanger prevent the formation of snow or ice in the expansion cylinder unless the vapour condensed by such interchanger were removed with regularity, for which no provision was made.

In attempting to carry these principles into practice, the Author was met with another set of conditions from the practical engineer who had to use the machines, and particularly the marine engineer—such as the necessity of having everything strong, with plenty of rubbing surfaces and material to stand wear, and the avoidance of using parts requiring frequent replacements, such as light piston rings, all of which, whilst favourable for a machine being worked continuously night and day for three or four months, are quite inimical to the reduction of friction.


The first machine constructed by the Bell-Coleman Mechanical Refrigeration Company of Glasgow, under the guidance of the Author, was built in 1877. It was intended entirely for marine work, and to work between the decks of a vessel where the vertical height does not exceed 6 feet 6 inches; it was also to be duplicated in all its parts, in fact, a double engine on one sole plate, so that if one half broke down the other could be worked by itself. This machine is shown in plan in Fig. 2, and consisted of two steam cylinders, A A, 10 inches in diameter and 18 inches length of stroke, two air-expansion cylinders, E E 14 inches diameter and 18 inches length of stroke, and four air pumps, P P P P, of 14 inches diameter and 18 inches length of stroke, all connected by a four-throw crank-shaft, with four piston-rods. The compressor is shown in section in Fig. 3, with its valves, which are, however, no more convenient and do not give better indicator cards than the form of valve shown in Figs. 3 a and 3 b, used by the Author in a previous machine erected for the compression of hydrocarbon gases to 150 lbs. per square inch.¹

An amount of water equivalent to five times the weight of air taken in was partly injected by the water-pump W into the com-

¹ Vide Transactions of the Institution of Engineers and Shipbuilders in Scotland, 1878-79. Vol. xxii., p. 103.

pressors, and partly in the form of a shower of rain into the air immediately after leaving the compressors, by a rose at the top of the tower S, filled with perforated plates, and up which the air ascended, and by which it was reduced to a temperature within 2° or 3° of that of the water, the latter falling downwards and being drawn off by automatic traps or ball-cocks. The air then descended to the floor level by the other tower T, filled also with perforated plates, and was then subjected to some of the cold air produced by the machine itself, by being made to traverse copper pipes arranged around the interior of the walls of the room of about 20,000 cubic feet capacity, being cooled. It was found that about 588 square feet of surface in the pipes caused a lowering of about 20° in 20,000 cubic feet of air passed per hour. The moisture liquefied by this arrangement was removed by automatic traps, and was sufficient to prevent any inconvenient amount of snow being formed in the expanded air when the working pressure of the air was 30 lbs. per square inch above the atmosphere, the air being previously cooled by water to 65° . The temperature of the meat room was 35° , the external air being about 70° Fahrenheit. A wet- and dry-bulb hygrometer suspended in the room never indicated more than 70 per cent. humidity during the continuous working of this machine for two months. Several carcasses of beef were preserved in splendid condition, and fish became stiff and their wet skins externally quite dry by a day or two's exposure to the atmosphere of the room. It was found, however, that the ratio of the steam cylinder capacity to that of the compressors was not such as to allow of the machine being worked with steam of 40 lbs. without the assistance of a steam-condenser, a condition which was essential on shipboard, as the full boiler pressure and the use of the condenser of the main engines could only be obtained at sea, and the machine was required to work in port occasionally.

Neither was the design so compact as was thought desirable, and it was then decided before putting anything on board ship to adopt a design which is shown in Fig. 4. Here it will be observed there were two compressors, P P, which were of 16-inches diameter and 16 inches length of stroke, each with its own expansion-cylinder of 12-inches diameter and 16 inches length of stroke, the two rods being connected to a double-throw crank-shaft, actuated by four small vertical overhead steam cylinders, with return connecting rods, each steam cylinder being 10 inches in diameter and 16 inches length of stroke. This arrangement was adopted with a view of getting the machine into a short length and a height not exceeding that between the decks of the ship,



and also of having each side of the machine complete, viz., air-compressor, air-expansion cylinder, and steam-cylinders, able, in case of accident to the other side, to be worked separately.

The towers into which water was introduced to complete the cooling of the compressed air are shown at S S T T. This machine was put on board the Anchor Line steamer "Circassia," in March, 1879, and connected with a chamber measuring about 18,000 cubic feet, including engine space and chamber walls, the internal walls of which were lined in the manner shown in Fig. 5. The moisture-depositing pipes of copper, which were to be exposed to the cold air of the chamber containing the meat, were arranged exactly fore and aft, so as to prevent their action being interfered with by the roll of the ship, the pitching of the ship being a lesser evil.

The Author went to New York with this machine to watch its behaviour, and returned in the following month with a small cargo; the machine was able to keep the room near freezing-point with sixty revolutions per minute. He returned to New York and back again with meat to the extent of four hundred carcasses of beef and large quantities of mutton, equivalent in value to about £8,000 sterling. This meat had been previously cooled to 35° in the chill-rooms of New York, and was landed here at about the same temperature. The machine ran a great number of voyages with similar cargoes, and finally giving place to a larger machine, was transferred to another steamer.

It may however be mentioned that in July, when the temperature of the harbour-water in New York was 85°, and the external air over 100°, it took all the power of the machine working at one hundred revolutions per minute to do the beforementioned work, which has been the basis of all subsequent calculations for a given room with such insulation as was then used. Matters had now arrived at the stage when it was deemed desirable by the owners of the Anchor Line to fit up the whole of their thirteen Transatlantic ships trading between this country and New York. After much consideration it was resolved to abandon the construction of machines in duplicate, and to trust to making a machine with an unusual factor of strength together with abundance of spare gear.

The design fixed upon is shown in Fig. 6. The first machine, however, of this type was placed on board the steamship "Strathleven," chartered by Messrs. McIlwraith, MacEacharn and Co., for an experimental voyage to Australia. The two compressors marked P P were 16 inches in diameter and 24 inches

length of stroke, the steam cylinder A was 18 inches in diameter and 24 inches length of stroke, and the expansion cylinder E 16 inches in diameter and 24 inches length of stroke. The water-pump W and water injection towers S T are shown. The moisture-depositing pipes with these machines were made of galvanized wrought iron expanded into cast-iron tube-plates, the top rows of tubes bringing back the compressed air from the far end of the pipes placed in the cold-room. These pipes were generally ranged fore and aft in the centre line of the ship, but in some cases, as in those of the "Strathleven" and the "Cuzco," they have been arranged next the ship's skin; they do not occupy, as a rule, more space than 300 cubic feet in a chamber of the gross measurement of 20,000 cubic feet, or a floor space of about $1\frac{1}{2}$ per cent. to 2 per cent. of the total area of the room. The machine-room seldom exceeds $7\frac{1}{2}$ per cent. of the space being cooled. In summer these machines have been able to reduce in a few hours in New York Harbour, with air and water temperatures of nearly 100° , the air of chambers 60 feet long, 40 feet broad, and 6 feet high, to below freezing-point, and at other times of the year they have been employed with equal success for chambers 100 feet long, 40 feet wide, and 6 feet high, internal measurement. Their average speed during a voyage has been about fifty to sixty revolutions per minute, and their average working air pressure 40 lbs. per square inch above the atmosphere.

Including those fitted up on the Guion Line, over two hundred voyages have been made with these machines, and they delivered 54,000,000 lbs. weight of meat into this country up to the end of 1881, of the value of about £2,000,000 sterling. They have always arrived in port in working order, and have never been stopped more than three hours for repairs at sea, the usual practice being to run them continually night and day from leaving New York to arrival on British shores.

As regards the one fitted on board the steamship "Strathleven," it arrived in London in February 1879, bringing 34 tons of mutton and beef frozen solid, being the first successful importation of fresh meat from Australia. The machine was only working a fractional portion of each day during the voyage, being connected with a chamber measuring internally about 4,000 cubic feet. Subsequent experience demonstrated that the same machine could have cooled a chamber of four times the size. In the case of the "Strathleven" and other Australian ships, the wall insulation was increased to 10 inches, and was formed of hollow walls filled with wood charcoal.

The log of this machine was kept by Mr. Matthew Taylor Brown, B.Sc., Glasgow, who went out to Australia in charge of the machinery. It contains much interesting information, particularly observations upon the minimum temperature of the air immediately after expansion, which fell to 100° below zero, with an air-pressure of four atmospheres absolute, and cooling water of 50° . Mr. Brown also made observations upon the freezing operations in Australia, and found that when a quarter of beef at a temperature of 70° was put into an atmosphere of about 10° Fahrenheit, its temperature at the expiry of five hours was 39° at the surface and 55° in the centre, and that twenty-four hours elapsed before the surface was frozen hard, the portions 6 inches below the surface being only about 50° ; in four days, however, the centre of the mass became reduced to a degree or two below freezing-point. It was also found that the conditions of bringing meat from Australia are very favourable for the working of the machinery, since the long run from Melbourne to the Equator in temperate waters allows the machine to get a thorough mastery of the cargo before arriving at the regions of the Red Sea.

The arrival of the "Strathleven" occasioned considerable excitement, not only amongst the general public but amongst engineers, some of whom, in their anxiety to reap the benefit of the experiment, recommended to shipowners arrangements of machinery which did not include any method of applying a portion of the cold produced by the machine for cooling the compressed air to below what the water can effect. Mr. T. B. Lightfoot described, to the Institution of Mechanical Engineers in January 1881,¹ how Messrs. J. and E. Hall, of Dartford, built such a machine of the Giffard type, as exhibited at Paris two years previously, and which, though large quantities of cooling pipes surrounded by water were adopted, and no water injection used, Mr. Lightfoot said could not be called "a dry-air machine," as it produced snow, but not to a sufficient extent to prevent its being worked. It was sent out to Melbourne, Australia, and a duplicate was forwarded to the Orange Company, near Sydney, and copied by Messrs. Robinson Brothers, Engineers, Melbourne, who fitted one on board the steamship "Protos," which brought the second cargo of meat from Australia. These machines circulate about half the quantity of air per revolution as compared with the Bell-Coleman machine used on the "Strathleven," and the one on the "Protos" occupied about four times the space the latter

¹ Vide Institution of Mechanical Engineers, Proceedings, 1881, p. 105.
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machine did, without taking into account the passages required to be left in the ships' holds for cleaning out the snow. Also Mr. Alfred Seale Haslam, after an attempt to do without using a portion of the cold developed by the machine itself for cooling the compressed air, in machines which he commenced to make after the arrival of the "Strathleven," has adopted this expedient before venturing to put machines on board a vessel.

During the year 1880 seven powerful machines were finished, under the superintendence of the Author for Bacon Curing Works in Waterford, Limerick and Hamburg. The plan and elevation of these machines are shown in Fig. 7. Each machine has one compressor of 23-inches diameter and 2 feet length of stroke, and one expansion cylinder of 17-inches diameter and 2 feet length of stroke on one rod and soleplate—the steam cylinder of 17-inches diameter and 2 feet length of stroke being on another soleplate, and the fly-wheel placed between the two. The aggregate power of the steam cylinders of these machines is equivalent to 700 HP. when working at full speed and pressure. The three fitted up at Waterford are worked with a pair of Galloway boilers, constructed for 75-lbs. steam pressure, and the steam cylinders have consumed not more than 3 lbs. of coal per I.HP. when the three engines work simultaneously, no steam condenser being used.

In the summer of 1880, the Consulting Engineer for the Colony of New South Wales, Mr. John Fowler, Past-President, Inst. C.E., was instructed to provide refrigerating machinery for a large chill-room measuring 80 feet \times 100 feet floor area, in connection with the Sydney Public Abattoirs, with a view to enable the inhabitants to be independent of the necessity of eating meat the day of its being killed. This chill-room was divided into two compartments, which were to be alternately used. Mr. Fowler arranged with the Bell-Coleman Mechanical Refrigeration Company to supply a machine having a pair of compressors of 24-inches diameter and 3 feet length of stroke. This was tried in the shops before being sent out, and then delivered air at fully 78° below zero with cooling water of 60° , the air pressure being 45 lbs., and the revolutions fifty per minute. This, at eighty revolutions, was calculated to be equivalent to delivering 120,000 cubic feet per hour reduced 150° Fahrenheit, or to a cooling power of about 8,000,000 heat-units abstracted in twenty-four hours. The work required of the machine was the cooling of meat not exceeding 100 tons per day from say 80° to 40° , the specific heat of meat being taken as about half that of water.

During the progress of this work it was determined by the

Furness Railway Company to erect chill-rooms at Barrow-in-Furness. The Author, after consulting with Sir James Ramsden, M. Inst. C.E., and Mr. Frank Stileman, M. Inst. C.E., designed the arrangement shown in Fig. 8, in which the machine-room with its drying pipes is on the right, and the plan of the chill-room on the left. The external walls are constructed of brick with a lining of charcoal in hollow wooden walls—light is admitted by windows, facing the north, glazed with blue glass. The floor is elevated and filled below with dry ashes, a good nonconducting material, not liable to be perforated by rats. The length of the room is internally 114 feet, its breadth 25 feet, and its height 10 feet 6 inches. The machine supplied was of the size shown in Fig. 6, and has been found to keep the room in summer time near freezing-point when filled with recently killed American cattle, slaughtered in the docks, in accordance with the regulations of the Privy Council.

About this time attention was directed to the construction of small machines for the cooling of ships' provisions. The Author designed the first machines which were used for this purpose, represented in Fig. 9, in which the compressor P, of 14-inches diameter and 12 inches length of stroke, and expansion cylinder E of 11-inches diameter and 12 inches length of stroke, were placed horizontally, and the steam driving cylinders AA vertically.

Two such machines supplied to the Orient Steam Navigation Company have now run to Australia and back half-a-dozen voyages in two of the largest vessels of the line, going by the Cape and returning by the Red Sea. These machines are attached to chambers of about 2,000-cubic feet capacity, which they keep at a temperature of 25°, besides providing ice for passengers' use, and do away with the nuisance of live stock on deck. These machines are to be now replaced by two powerful Bell-Coleman cargo machines, of the same size as those on board the ss. "Cuzco." A similar machine was put on board the Peninsular and Oriental Steamer "Kaiser-i-Hind," which was very successful the first voyage and kept a meat chamber at about 25°, and the ship's drinking water at about 45° during the voyage of one hundred days, the machine being worked the whole time at about two-thirds speed. Another design, however, was adopted by the Author for the Peninsular and Oriental steamers, shown in Fig. 1, the largest steamers of their fleet being so fitted up. Subsequent experience has, however, indicated that the first design is a very excellent one if the steam cylinder and pump are put on the horizontal rod, and the expansion cylinder on the vertical rod, which distributes the strains


better, besides allowing of the moisture depositing pipes being packed in the soleplate, instead of forming a portion of the walls of the room being cooled (Fig. 10).

Another form of small machine adapted for cooling ships' provisions is shown in Fig. 11, and can be used either with or without the steam surface condenser. The compressor P of this machine is 14 inches in diameter and 18 inches length of stroke, the steam cylinder A, 12 inches in diameter and 18 inches length of stroke, and it has been fitted up with a steam surface condenser C, on a Bermuda and New York Steamer, and, without a steam surface condenser, for cooling the provisions of the Spanish Mail Steamer "Antonio Lopez" trading between Spain and the West Indies. A machine of this size enables the provisions to be kept cool by working only a few hours daily, thus obviating the necessity of more than one man to attend it.

The Peninsular and Oriental Company have also tried a machine supplied by Messrs. J. and E. Hall on the steamship "Clyde," and one made by the Giffard Refrigerating Company on the steamship "Thames," the chambers with which they were connected being much smaller than those fitted up on the "Rome" and "Carthage."

Mr. Lightfoot suggested about this time a method of employing a portion of the cold produced by the machine for removing moisture from the air, in which extended metallic surfaces containing the compressed air are placed between a primary and secondary expansion cylinder, instead of, as in the Bell-Coleman process, the extended metallic surfaces being between the compressor and a single expansion cylinder. Mr. Lightfoot claims that this is a more effectual method of separating the moisture; but so long as the simpler method of using one expansion cylinder suffices, the complication introduced by the double expansion system is not desirable.

In regard to the import of meat from the Australasian colonies, up to the end of 1881, eight vessels had been fitted up, since the first cargo was brought over, by the Bell-Coleman Mechanical Refrigeration Company, viz., the "Cuzco," "Dunedin," "Orient," "Garonne," "Catania," "Europa," "Protos," and "Sorrento." Measured by the cubical contents of air taken in per hour by their respective compressors, the "Cuzco" and the "Dunedin," fitted to the Author's designs, are the most powerful. These machines each contain a pair of compressors of 21 inches diameter and 24 inches length of stroke double action, and take in 19.2 cubic feet of air per revolution, or 92,000 cubic feet per hour at eighty revolutions per minute. They are adapted for cooling to 25° Fahrenheit



a gross space of 34,000 cubic feet in the tropics, of which the machine-room, including the drying pipes, will occupy 2,500 cubic feet, the insulating walls about 7,500 cubic feet, leaving a net capacity of 24,000 cubic feet, which, by careful packing, will hold dead weight of meat equal to 250 to 300 tons. For the first voyage they have been worked in connection with smaller rooms, which have only required two-thirds of their time and two-thirds of their proper speed. Fig. 12 shows this machine connected with a chamber of the size just mentioned.

The vessels "Orient," "Garonne," and "Catania" have been fitted up by the Haslam Engineering Company, of Derby. The machine in the "Catania" was, however, taken off after the first voyage. These machines, in the form of their soleplate, in the relative position of the cylinders and crank-shaft and general appearance, are almost an exact repetition of the designs of the Author, from which they differ chiefly in occupying a little more space and in the method of employing the cooling water, viz., by passing the compressed air through pipes cooled externally by water instead of by direct injection. This, however, has not prevented snow being produced, nor obviated the necessity of the makers using a portion of the cold produced by the machine itself for cooling the compressed air, below what can be accomplished by the water.

Each of these machines has a pair of air compressors of 17 inches diameter and 2 feet length of stroke; they take in about 41·1 cubic feet of air per revolution, and are therefore only 73 per cent. of the power of the machines in the "Cuzco" and "Dunedin" at similar air pressures and revolutions.

The "Protos" and "Europa" have been fitted up by Messrs. Robinson Brothers, who took for their model Giffard's arrangement.

The machine on board the "Protos" consisted of a single action compressor of 30 inches diameter and 20 inches length of stroke, and a single action expansion cylinder of 27 inches diameter and 20 inches length of stroke, taking in about 8·2 cubic feet of air per revolution. Whilst occupying three times the space of the "Cuzco" machine, it possesses only 32 per cent. of its power on account of the construction not allowing of the machine being worked at more than sixty revolutions per minute. In the "Europa" there is a repetition of this design somewhat modified, three similar sized compressors and expansion cylinders having been crowded into the space previously occupied by one; and also, the Author is informed, an arrangement for utilising some of the

cold produced by the machine to prevent the formation of snow which had been troublesome in the "Protos."

The "Sorrento" has been fitted up by Messrs. Hick, Hargreaves and Company, of Bolton. It contains two independent machines, occupying a room of about 4,000 cubic feet capacity, each machine having a compressor of 21 inches diameter and 18 inches length of stroke, and an expansion cylinder, worked with Corliss valves, on the same rod, which is attached to a crank-shaft on a horizontal bed containing pipes in which the compressed air is cooled; the motor is an oscillating steam cylinder placed vertically at the crank-shaft end of the soleplate. The two machines take in jointly about 14.4 cubic feet of air per revolution, and have therefore 75 per cent. of the power of the "Cuzco" machine at equal revolutions; and Messrs. Hick, Hargreaves and Company have adopted the arrangement of applying some of the cold produced by the machine to aid the cooling of the air.

All these calculations leave out the allowances for clearances, which are arbitrary, and for which no uniform practice has been established. The Author has always adopted the figure used by Professor Colladon, of Geneva, in his calculations of the compressed-air machinery for the Mont Cenis tunnel; that is, to take the net efficiency as 70 per cent. of the theoretical, though he has been informed that some makers of machines quote them without any allowance. At best, however, this is a very uncertain way of arriving at the performance of the machines, since the work done will be determined by the weight of air passing through the machine, its volume being a variable quantity dependent upon temperature. The ratio of the expansion cylinder to that of the compressor should be such, that the terminal pressure at the end of the process is slightly above that of the atmosphere rather than below. Suppose an air compressor which theoretically takes in 100 cubic inches of air, and practically only 70, and in addition that this air is reduced from 80° above to 70° below zero, it will be practically reduced in bulk in the proportion of the absolute temperatures 540° and 390°, or to about 50 cubic inches. It therefore could not possibly give back more than one-half of the power employed in compression, and the cooler it becomes the less bulk it will occupy at the end of the stroke, and therefore the less power will be restored in proportion to that exerted in compression. To measure, therefore, accurately the work being done by a machine, it becomes necessary to take observations: 1° of the HP. being exerted by the steam cylinder; 2° of the temperature of the compressed air immediately before expansion; 3° of its

temperature immediately after expansion; 4° of the terminal pressure of the expanded air as read from an indicator card.

The calculation presupposes that the compressed air has been cooled to the temperature of the water available for cooling it, and is then as follows:—

First, to arrive at the weight of a cubic foot of air at the end of the stroke, let

W = weight of a cubic foot of air in lbs. avoirdupois.

p = pressure of air in lbs. absolute per square inch as read off an indicator card.

T = the absolute temperature in degrees of Fahrenheit at the moment of discharge.

then ¹
$$W = \frac{p \times 2.704}{T}.$$

Having now ascertained the weight of the cubic foot of air, it merely remains to multiply it by the number of cubic feet swept out of the cylinder in a given time (say one hour), then by the specific heat of air, and the weight of water is arrived at which could be cooled through the same range as the air has been cooled. This can then be calculated as heat-units, or as the Author prefers, in terms of ice at 32° produced from water at 32°.

The formula now becomes

$$w = \frac{W_1 \times S \times R}{L},$$

in which

W_1 = weight of air discharged per hour.

S = specific heat of air (0.23).

R = range of cooling in degrees of Fahrenheit.

L = latent heat of ice.

w = lbs. of ice at 32° produced from water at 32° per hour.

Taking a practical illustration, three sets of cards are shown in Figs. 13 to 21, being the records of a voyage of the 32nd machine erected under the supervision of the Author, the first set being taken in the neighbourhood of the Cape of Good Hope, the second in the Red Sea, and the third in the Mediterranean.

The average HP. by the steam-cylinder cards was 76.8, the average range of cooling was 140° Fahrenheit after leaving the drying pipes or interchanger, the average air pressure 40 lbs.

¹ Vide "A Manual of Rules, Tables and Data," by D. K. Clark. 8vo., Lond. 1877, p. 850.

above the atmosphere, and the equivalent of ice is 12·9 lbs. per hour per HP., the revolutions being fifty-eight per minute.

In another set of cards, Figs. 22, 23, 24, taken at Messrs. Henry Denny and Sons' works, the average HP. of the steam cylinder was 68, and the ice equivalent in lbs. per hour per HP. 11·25 lbs., the revolutions being seventy per minute.

Messrs. Denny's engineer reports the coal consumption without a steam condenser as about 3 lbs. per HP.; that of the steamships would no doubt be less, probably $2\frac{1}{2}$ lbs. coal per HP., so that these machines give an equivalent of about 5 lbs. of ice to 1 lb. of coal, and this is by no means the limit of efficiency in such machines, as by compounding steam cylinders, and resorting to other expedients, it is not impossible to reduce the consumption of coal to 2 lbs. per HP., under which circumstance the machines should give a much higher equivalent, possibly as high as that afforded by an ammonia machine, taking a fair average of its working.

It is right, however, to observe, that difficulties arise in getting such results with machines dealing with less than 20,000 cubic feet of air per hour. Machines of less capacity than 10,000 cubic feet per hour require fully 65 lbs. air pressure for a range of cooling of 150° , which, with machines dealing with 50,000 cubic feet per hour, can be got with 45-lbs. pressure. The friction encountered in proportion to work done is greater the smaller the size of machine, and is liable to be increased by very trifling causes, such as tight glands, thick piston-rods, &c. The effect of a tight piston in the expansion cylinder can easily be calculated, if it is supposed that a piston block of 100 inches area through being too tight requires a force of 2 cwt. to propel it from one end to the other, not only requiring power to be overcome, by actually developing heat in proportion to the friction. Small machines also present much larger metallic surfaces to the atmosphere in proportion to work done than the larger machines, and are therefore liable to absorb heat, especially in tropical climates.

The following Table shows the range of temperature through which compressed air should be reduced, with degrees of expansion, the terminal pressure being supposed to be not under that of the atmosphere:—

Degree of Expansion	16	8	7	4	3	2
When the compressed air is at 60° } the range of cooling should be . }	355°	303°	271°	230°	188°	131°
When compressed air at 90° the } range of cooling should be . . }	375°	320°	287°	243°	199°	138°

Another practical point may also here be mentioned, viz., the desirability of reducing the number of compressor valves to a minimum, so as to avoid too many parts liable to get out of order. On the other hand, a careful comparison of indicator cards has convinced the Author that a number of small valves, rather than a few large ones, is the most effectual way of constructing a compressor, prevents the cushioning of air previous to expulsion, and diminishes the HP. required to drive a machine.

It now only remains to add a few words upon the application of this class of machinery to public buildings, hospitals, &c., and to Indian and other tropical residences. Experience has demonstrated that machines of power sufficient to cool 100,000 cubic feet of air per hour through a range of 150° can be worked with a steam cylinder indicating from 100 to 150 HP., or the consumption of $\frac{1}{3}$ th of a ton of coal per hour. The attendance upon such a machine would not cost more than 1s. 6d. per hour, the lubrication 6d., and the interest on capital, say 1s. per hour, so that the whole 100,000 cubic feet of air would not cost more than say 8s. 4d., but being so excessively cold, it could be mixed with 400,000 cubic feet of uncooled air, and this would then give a supply of air per hour to 1,000 people at the rate of 500 cubic feet per head per hour cooled 80° Fahrenheit below the external atmosphere, a very excellent ventilation, at a cost of $\frac{1}{10}$ th of a penny per head.

In private houses air cooled to 50° below zero could be used without the least difficulty, by being made to flow into sitting- and bed-rooms through stove-like reticulated structures similar to those used for warm air in hotels. Such air would only be 100° below the normal temperature, which is no more extraordinary for sitting or sleeping near, than in the case of warm air, which in the vicinity of a stove or fire is 100° hotter than normal, and over $1,000^{\circ}$ hotter at the centre of combustion.

But the laws of thermodynamics are not against, but very greatly in favour of, machines worked within reasonable ranges of temperature for cooling buildings. The Author hopes that these and other developments of air refrigeration will not escape the attention of members of this Institution, to whom he must express his thanks for having been permitted to bring the matter so fully before them.

The Paper is illustrated by several figures and diagrams, from which Plates 1, 2 and 3 have been prepared.

[Discussion.]

Discussion.

Frederick
Bramwell.

Sir FREDERICK BRAMWELL, Vice-President, remarked that a Paper treating of apparatus designed with the object of transporting food for long distances in a fresh state—for preserving it on board ship for the use of the crew, dispensing with the carriage of ice and of live stock—was one dealing with a subject of the highest importance; and further, as shown in the closing paragraphs of the Paper, there was the probability that those persons who were compelled to reside in hot countries, might, by such apparatus as had been described, be there as effectually enabled to reduce the temperature of their dwelling-houses, as it was possible here effectually to increase the temperature of dwellings in cold weather to a point which was agreeable to those who had to live in them. But although he felt sure it would be a waste of time to dilate upon the importance of the subject, he might be allowed to say a few words on the value of the Paper as regarded from another point of view, namely, that probably never had one been submitted which made more strikingly clear the necessity that the successful engineer of the present day, and still more the successful engineer of the future, must be a man competent to apply to the pursuit of his profession the highest scientific truths. The Paper showed how the very utmost secrets of thermo-dynamics were applied in practice for common use, and thus it was a Paper which would admit of an extremely interesting discussion. It would admit of discussion by the purely scientific man; it would admit of discussion clearly by the engineer competent to apply science to engineering; and yet it would still admit of discussion by those who had not made science their study, but had confined themselves to the more practical part of engineering, inasmuch as there was plenty in the actual detail of the machines which could be discussed entirely from that point of view.

Coleman.

Mr. COLEMAN said he had not much to add to the written contents of the Paper, except to supply an omission with reference to the indicated HP. of the indicator diagrams. The average indicated HP. of the cylinders of cards, Figs. 13, 16, 19, taken during the voyage to Australia and back was 76; the average indicated HP. of the air expansion cylinders was 57; and the average indicated HP. of the compressors 118. The total driving power was therefore 133 HP.; the total resistance was 118 HP., and the difference between the two was 15 HP., and indicated the amount of friction, which was about 12 per cent. In engines for waterworks and


so on, the friction was frequently as much as 20 per cent., so that, when the friction was only 12 per cent. with machinery like that, it appeared to him that it was a very reasonable amount. That was for the larger machine; for, as he had already pointed out, the results obtained from the smaller ones were not equal to those of the larger machine. There was reason to believe that when yet larger machines were made, a still better result would be obtained.

Mr. A. SEALE HASLAM said, for a long time past he had given a considerable amount of attention to the development of this very important subject of mechanical refrigerators. So far as had been pointed out, he thought he clearly understood the principles adopted by the Author, but his own experience convinced him that the reverse of the operation would perhaps meet the case better. He had found that the injection of water, as adopted by Mignot, Giffard, and other eminent men who had experimented in that direction, was open to grave objection; and he would point out some of the objections which he had found by experience. Assuming that the machine illustrated by the Author was being worked at a pressure, say of 45 lbs. above the atmosphere, the temperature of the air under compression would be probably about 300° Fahrenheit. The air at that temperature had great affinity for the water that had been injected, and therefore became surcharged with vapour. This appeared to him to be one of the chief objections to injecting water for the purpose of cooling air. After passing from the cylinders the air was brought into contact with water in the tower. He presumed the air entered at the bottom of the tower, and a spray of water was admitted at the top, so that the air again underwent a washing process, and, of course, if not sufficiently cooled took up further moisture. The air was then passed through another tower for the purpose of extracting water. Whether this was effected or not he would not say, but the system of injecting water into air under compression appeared to him objectionable if the end could be obtained by other processes—if the sensible heat could be destroyed. His experience had shown that, with a properly constructed compressor, a cylinder-jacket with the covers effectually jacketed in order that the water might circulate freely all round the cylinders, air admitted on these conditions was not surcharged with water; but starting, say at a temperature of 300°, was cooled to 240° or 230° more or less, according to circumstances. Air cooled in a compressor properly jacketed, and then admitted into a surface cooler where the sensible heat could be removed to within a few degrees of the initial temperature of the water, must be more effectual for the purpose in view, that being,

Mr. Haslam. getting air under pressure, eliminating the sensible heat, and expanding air against resistance for the purpose of reducing the air to a low temperature. The most effectual way of removing sensible heat was by surface cooling; the air was not surcharged with vapour as it was under the process described by the Author of the Paper. He also found that salt water injected into a cylinder had a damaging effect, not only upon the valves and the springs but also upon the piston; and of course it was most essential in air-compressing machinery that the piston and valves should be always in a state of efficiency. He believed he had shown that air under pressure, with the sensible heat taken out by surface cooling, must be in a better state for passing through the air expansion cylinder, and must contain less aqueous vapour than air that was surcharged with water injected during compression. It was stated in the Paper that Mr. Haslam, "after an attempt to do without using a portion of the cold developed by the machine itself for cooling the compressed air . . . has adopted this expedient before venturing to put machines on board a vessel." This was not the case. He supplied many machines without the use of cold air acting upon the special apparatus made and patented by him, and called a "Collector and Separator." When such apparatus was used, it was employed for a different purpose, and was of a different construction to the "Bell-Coleman" moisture-depositing apparatus. If air at a temperature below 32° Fahrenheit was applied to the Bell-Coleman apparatus, it must freeze up and stop the working of the machine. In the Haslam apparatus, the machine was so constructed as to use air without the injection of water, and the bulk of the aqueous vapour contained in the air was deposited prior to reaching the "Collector and Separator." The construction and arrangement of this apparatus was such that it could not freeze up, and by its use air might be reduced below freezing-point prior to expansion, thus rendering the machine effective and economical in working. The small refrigerators for cooling provision stores were as effective in producing cold air with equal air-pressure as the large machines. He did not find it requisite to raise the air-pressure above 45 lbs. on the square inch to reduce the temperature of the air to 60° below zero; it was, however, stated in the Paper that the air-pressure in small machines should be raised to 65 lbs. on the square inch. As to the room required, the Haslam machine, which discharged 50,000 cubic feet of air per hour, occupied a deck space of 135 square feet, or 776 cubic feet; and a small machine, which discharged 7,000 cubic feet of air per hour, occupied a deck space of 38 square feet, or 250 cubic feet.

Mr. F. N. MACKAY wished to call attention to the Author's statements regarding the application of machines worked by ether for cooling air through the medium of pipes. He said that pipes placed in a room that had to be cooled became entirely covered with a coating of ice, which he rather graphically represented as being like enamel. Now, when the machine was put to work in a room of that description, and with machinery of that description, the temperature was gradually lowered, and it was impossible for ice of this character to form upon the pipe unless an alteration of temperature took place either in the contents of the pipe, or in the room in which the pipe was placed. Therefore if pipes were used for cooling a room, the temperature of the room must be allowed to rise considerably above 32° before a coating of that class of ice would be formed upon the pipe. In fact, when machines were used for cooling air, or, more correctly speaking, air-spaces, the ice that formed resembled hoar frost, and as long as the machine continued at work, this increased very slightly, according to the amount of moisture in the room. That moisture, when a place was filled with meat, was not, of course, so great as to produce a layer of 2 or 3 inches of ice on the pipes. Mr. Mackay had not applied his machine to meat cooling, but it had been supplied extensively for cooling rooms and in breweries for reducing the temperature in the fermenting vessels. The machines were kept at work during three or four days, and the temperature was thereby reduced to about 40° , instead of about 70° , thus enabling the brewer to carry on the process of fermentation in a cool atmosphere during the whole of the summer. He had seen pipes used in stores cooled with this class of machinery; they had been at work for months together, and the thickness of ice on the pipes had only been $\frac{1}{4}$ of an inch. But even if the ice did form an inch in thickness, it thereby increased the surfaces, and so increased their action on the air. He had proved that ice could be reduced to almost any degree of temperature by a thermometer in the centre of a block 12 inches thick. The brine from which it was frozen being circulated in cells had a temperature of about 15° , and when the block was completed the temperature was 20° , but in three or four hours the inside of the block, according to the thermometer, registered within 1° the temperature of the brine. Bringing this to bear upon the point under discussion, it seemed that brine-pipes in a cold store acted as a reserve of cold, so that the machine could safely be stopped working for two or three hours. In a great many places it was not advisable to have a constant circulation of air through a room; machines were applic-

Mr. Mackay. able to various purposes, and the same machine was not capable of being applied to everything. There was one other point he wished to mention. The Author stated that the HP. in an experiment at Messrs. Denny's works was 68, and produced 11·25 lbs. of ice per HP. per hour. Taking that roughly, it would mean 70 HP., producing $11\frac{1}{2}$ lbs. of ice per HP., would make 800 lbs. of ice per hour. A large ether machine, erected by Mr. Mackay's firm in 1880, produced 22 tons of ice every twenty-four hours, and indicated 64 HP., which was at the rate of 3 HP. per ton of ice produced in the twenty-four hours, or 31·1 lbs. of ice against Mr. Coleman's production of 11·25 lbs. This firm had shipped a great many machines to India, the average indicated power for a 5-ton machine being 25 HP. per twenty-four hours, being 5 HP. per ton of ice produced. The large machine in this climate was able to produce ice more economically than the same machine in a warm climate like India, where the ice was made from water at the temperature of 80°; but still this gave 18·6 lbs. of ice per HP., considerably in advance of 11·25 lbs. produced by the cold-air machine. The statement that the coal consumption in Messrs. Denny's machine was 3 lbs. per HP., giving an equivalent of 5 lbs. of ice per 1 lb. of coal, which made (5 lbs. \times 3 lbs.) 15 lbs. of ice per indicated HP., must be a mistake, since this machine, according to the results previously mentioned, produced but 11·25 lbs. of ice per HP. It should therefore be 3 to 4 lbs. of ice per 1 lb. of coal, instead of 5 lbs. The ether machines made by his firm produced 10 lbs. of ice for the large ether machine, and 6 lbs. of ice for the 5-ton machines in India, per 1 lb. of coal used. The Author stated that 100,000 cubic feet of air could be cooled through 150° per hour for 8s. 4d., which, when mixed with warm air in proportions of 4 to 1, would supply 500,000 cubic feet of air at 30° Fahrenheit, adding "a very excellent ventilation." He could not agree to this; no person in India could live long in such a temperature as that. Even if such results could be obtained, it would be undesirable and unnecessary to reduce the temperature to such an extent. Taking the temperature in India at 100°, it would be sufficient to reduce this to 70°, which could be done without lowering the air admitted into the room to 50° below zero. But an air machine could not be then employed, as the volume of air would be too great to be passed through the machine, and only cooled 30°. Therefore cooling pipes had the advantage for this kind of work, for more than one reason; not only did they effect the cooling of the air to just the required temperature, but they did so without draughts or currents, which would be a very disagree-



able element in the air machine when cooling a room by pumping Mr. Mackay into the space to be cooled air at a temperature of 50° below zero. Moreover, the desired temperature of 70° could be obtained by pipes, at a far less working cost than 8s. 4d. per hour for 1,000,000 cubic feet, as the 100 to 150 HP. required for this by the air machine would, if used for his ether machine, produce 40 to 50 tons of ice per twenty-four hours, or about $1\frac{1}{2}$ ton to 2 tons per hour, being much in excess of the quantity required to cool this volume of air through 30° . At the commencement of the Paper the Author pointed out the laws that should regulate artificial cooling, and certainly the use of a machine producing air at 50° below zero, when only a temperature of 70° above was required, was not in accordance with them. He agreed with the Author that "by far the most economic results, as regards coal consumption, will be obtained when machines are worked within a small range of temperature." This was why his ether machine showed such favourable results when compared with cold-air machines used for like purposes, and when like temperatures were required. The temperature of 20° to 30° for a cold room was well within the limit of the power of his machines, seeing that the ice they so economically produced was made some 10° below these temperatures; and the use of the brine, in the ice tanks, to cooling air by pipes, was only another application of the machine, and equally good results could and had been obtained by them when employed for this purpose.

Mr. E. HESKETH, in reference to the coating of pipes in the Mr. Hesketh chamber with ice, said there was no doubt that the pipes, though not actually coated with ice, would be covered with hoar-frost, and this hoar-frost, or snow, would have the effect of partially preventing the absorption of the heat from the chamber. The non-conducting property of hoar-frost was very apparent when testing the temperature of cold-air machines with a thermometer. The Author was rather inclined to lay down the law that these machines would not work without the use of the drying pipes, and referring to Mr. Haslam, he said: "Also Mr. Alfred Seale Haslam, after an attempt to do without using a portion of the cold developed by the machine itself for cooling the compressed air, in machines which he commenced to make after the arrival of the 'Strathleven,' has adopted this expedient before venturing to put machines on board a vessel." Mr. Hesketh might refer to some machines put up by his firm, Messrs. J. and E. Hall, of Dartford, without drying pipes; in fact, without any means for preventing the deposit of snow, and they had no difficulty, by constructing proper valves and snow-boxes, in sending the air into the chamber in as dry a condition

Mr. Hesketh. by these as by any other machines. It stood to reason that all machines must deposit some snow, whether they had drying pipes or other means of depositing moisture, because they could only cause a deposit of moisture down to a certain temperature above freezing-point, and then the residual moisture must be carried forward and deposited as snow. He should like to ask the Author whether that was not so, to some degree, at all events, with his machines; whether he had not to clear snow away from the passages just outside the expansion cylinder, where the air was discharged? Mr. Haslam had already referred to the adoption, by the Bell-Coleman Company, of injected water in their compression cylinder. That method was objectionable, principally on account of the wear and tear thereby occasioned; he referred more especially to machines on board ship, where the injection water was sea-water, which had undoubtedly a deleterious influence upon metals. In relation to that, he should like to ask the Author the condition of the refrigerator of the "Kaiser-i-Hind" after its return from its first voyage; whether the valves and pistons, and the whole of the compression cylinder were in really a thorough good working condition. The Author referred to a machine, sent out by Messrs. Hall to Melbourne, and it might be thought, from the context, that he went on to explain it; but he was really describing Messrs. Robinson Brothers' machine in the "Protos," which, although it was said to be a copy of Hall's machine, was rather an unfortunate one for Messrs. Robinson. The Author said: "The Peninsular and Oriental Company have also tried a machine supplied by Messrs. J. and E. Hall, on the steamship 'Clyde,' and one made by the Giffard Refrigerating Company on the steamship 'Thames,' the chambers with which they were connected being much smaller than those fitted up on the 'Rome' and 'Carthage.'" It was rather hard to put it in that way. The Peninsular and Oriental Company had not only tried one of their machines, but had bought and paid for it, so that it might be concluded they were satisfied; and, in fact, so satisfied were they that they had ordered two more machines for other steamers.

Dr. Siemens. Dr. C. W. SIEMENS said the question that had been brought before the Institution was one of considerable engineering and public importance, and he was glad to see it brought forward in such a clear and efficient manner. The subject was not one of recent date, but had occupied the minds of many men for a considerable number of years. The Author had been good enough to mention his name in connection with a proposal which he had made twenty-five years ago to the effect of superadding

to the simple play of the two pumps—the compressing and the re- Dr. Siemens
expanding pump—an interchanger of temperature. That suggestion, as it presented itself to the Author, was published only in a provisional specification of a patent which had never been specified finally; but more than that had been accomplished, and perhaps it might interest the members to know exactly what he had done. Dr. Gorrie, an American, had patented and brought to England a certain scheme, which had been taken up by Mr. Wollaston Blake and a few other gentlemen in London, who erected plant which was perfect in all its details. The engine had a 25-inch cylinder and 5 feet stroke; the compressing and re-expanding pumps were made by James Watt and Co., and had been erected somewhere in the north of London; but when it came to be tried it was impossible to get a depression of temperature exceeding 20° Fahrenheit. That being the case, after several ineffectual attempts to improve the result, he was asked to examine the machine and report to the proprietors. He had lost sight of the report, but Mr. Wollaston Blake had sent him a copy with the drawings and suggestions which he had made for improving the efficiency of the engine, and these would be appended to his remarks (see p. 179, *et seq.*). The report was of some interest, as it went very fully into the principles underlying the question of refrigeration, and the causes of the non-realisation of those results which should have been effected. It seemed curious that, from the *à priori* examination and calculations which he made, he had come to the conclusion that the temperature could not be depressed more than 20° by the machine, that when that reduction of temperature was reached the loss of effect would exactly balance the beneficial result; and the actual trial corroborated that statement. The Author had, perhaps, hardly given him credit for the labour which he had spent upon the subject. He not only devised the temperature interchangers, which was the most essential feature in the whole process, and without which no efficient results could be obtained, but he had fully recognised the antagonistic effect of aqueous vapour in the air dealt with. The loss of effect “by throttled passages” he had given at 10·08 HP. That required some explanation. Dr. Gorrie evidently wished to avail himself of the expansive force of the compressed and cooled gases before they were discharged again; but he did not conceive that the whole effect of the machine depended upon the heat (utilised negatively) in that final expansion; and in order to be sure, as he thought, doling out as it were the compressed air to the expanding cylinder, he introduced a throttle-valve into the

Dr. Siemens. compressed and cooled air; and instructions were given to wire-draw that valve as much as possible on the supposition that after all the safe plan of gaining refrigeration would be to expand air through the throttle-valve, that was, through a contracted orifice. Dr. Siemens showed that contraction was the worst thing that could happen—that by merely expanding air without exacting work from it, no depression of temperature would ensue. By friction and useless agitation of the fluid, the loss was 3 HP., by condensation of vapour, 1·90 HP. That, of course, was a very fruitful source of loss. If the air was compressed and then not sufficiently refrigerated, the vapour which it contained would, on re-expansion and final cooling in the expansive cylinder, not only condense, but be converted into ice. The vapour which went in as steam would come out as ice, and the whole of the latent heat taken up in that double process of conversion was entirely lost. That loss in some of the earlier attempts was fully equal to the whole useful effects that could be expected. But the greatest loss of all was incurred in allowing the cold air to leave the apparatus at the minimum temperature. Dr. Siemens suggested that a current exchanger should be supplied; that the cold air after it had done its negative work, so to speak, should pass up through spaces surrounding a number of vertical tubes, and that the cold compressed air should pass through the tubes themselves in the opposite direction and exchange temperatures. In that way $7\frac{1}{4}$ HP. could be saved. It was shown in the report that a very economical result might be obtained by observing those precautions. Attached to the report were diagrams taken from the three cylinders, and a sketch showing the kind of apparatus which was then proposed, and which, he thought, in all material points was similar to the machine brought before the members by the Author of the Paper. There was, however, one point in which he still dissented from the knowledge and experience of the present day. He had stated in the report that as ice-making was really negative work there could be no absolute limit to the effect to be produced by heat in that direction. It was true that great men like Dr. Clausius, Sir William Thomson, and Dr. Joule had established a certain equivalent, an equivalent which was perfectly true if the heat generated in the mechanical process of compression was treated as waste. But by means of the regenerator it was possible to recover, at any rate, a large proportion of the heat so produced at the minimum temperature attained in compressing the air. The ice produced was, therefore, only evidence of a transfer of heat from the fresh water to air or water raised to a high temperature. And in this

respect the operation of freezing differed very essentially from that of power-producing, when a given amount of heat must absolutely disappear. The report might perhaps be interesting, as it gave the particulars of the views which he then entertained, and of the theoretical conclusion at which he arrived—a conclusion which, he had little doubt, though it was not now fully admitted, would be admitted before the subject was done with. The Paper dealt with the question as it stood at the present day in a very able and proper manner, and the applications which would flow from a cheap and ready mode of reducing temperature to any desirable point could not be easily overrated.

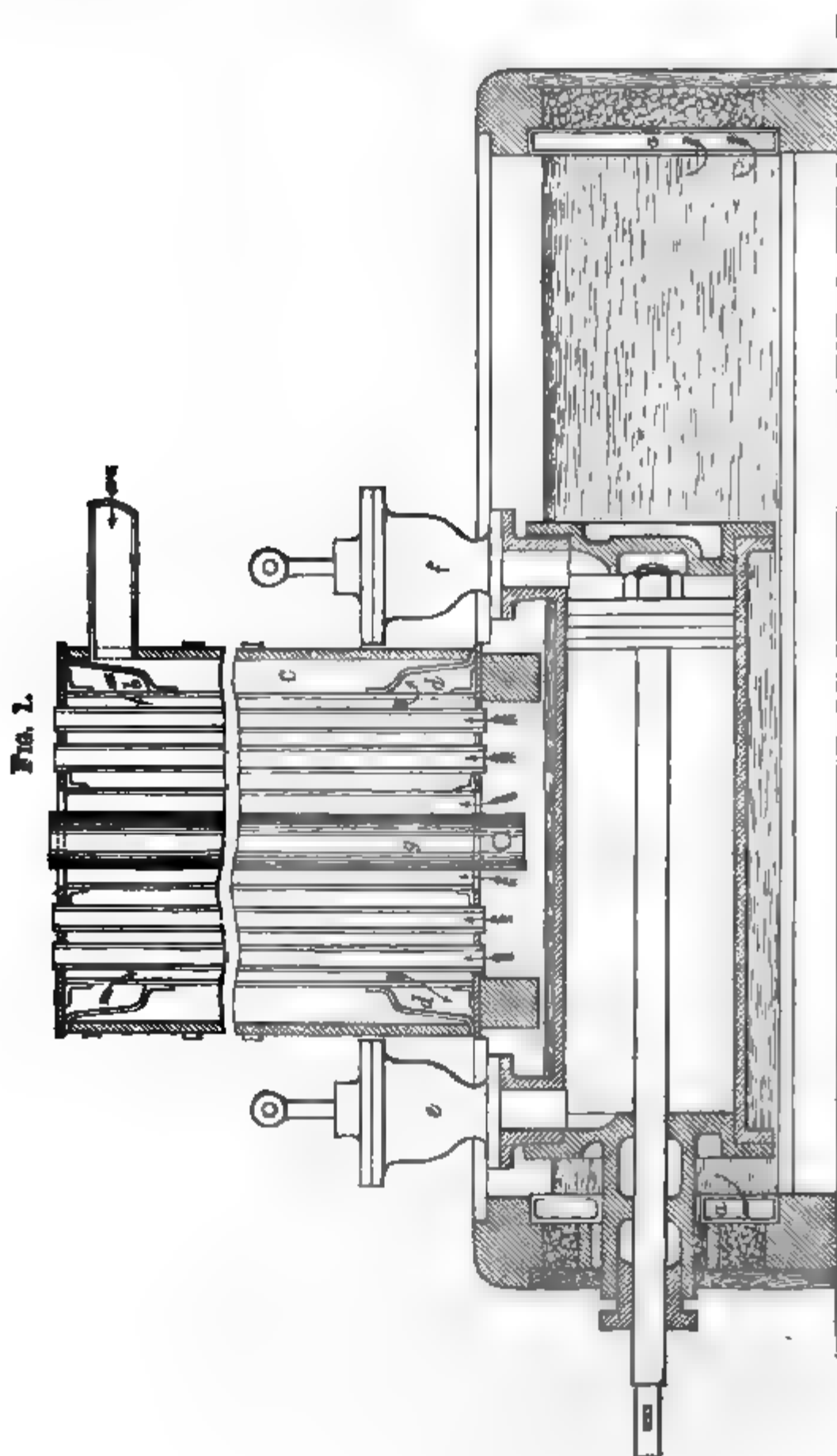
Report on the performances of Newton's Patent Refrigerating Apparatus, with suggestions for improving the same.

Having examined your apparatus for the artificial production of ice on your premises at Camden Town on the 8th instant, and having examined carefully into the capabilities of the principles involved, and into the causes of its present lack of success, I have to report thereon as follows:—

Description.—The apparatus (Fig. 1) consists of a horizontal condensing steam-engine of 32 inches diameter of cylinder, and 5 feet length of stroke, in excellent condition, by Messrs. James Watt and Company, which imparts motion to a crank-shaft with two additional cranks, which are connected with the pistons of two air cylinders of 4 feet 6 inches stroke, and of 21 inches and 19 inches diameter respectively. The piston rods of the air cylinders are carried horizontally through the cylinder bottoms, and are each of them attached to a second piston 4 inches in diameter, working in the barrels of double-acting pumps, which inject at each stroke their fluid contents into one extremity and the other of their respective air cylinders. The larger air cylinder (of 21 inches diameter) compresses atmospheric air into an upright receiver, where it is allowed to separate from the injected water, the water issuing from the bottom through a ball-tap, and the comparatively dry air proceeding through a pipe leading from the tap into a larger horizontal receiver or reservoir, which is provided with a mercurial pressure gauge indicating 55 lbs. effectual pressure per square inch when the apparatus is at work.

A copper pipe (of 3 inches diameter, and provided with a stop valve) leads from the receiver to the second air cylinder of 19 inches diameter, wherein the compressed and cooled air is allowed to expand again down to atmospheric pressure, and being mixed in the expanding cylinder with a spray of injected brine (by means of the second injection pump) it is expelled into a large cistern containing about 500 gallons of brine. The injected brine here subsides, and the expanded air escapes freely into the atmosphere. It appears from records of experiments made on the 28th and 29th of April, and on the 18th of May last, that the water injected into the compressing cylinder was raised uniformly from $2\frac{1}{2}^{\circ}$ to 8° Fahrenheit in temperature, whereas the brine in the cistern (500 gallons) fell gradually in temperature from 2° to 3° per hour at first, but diminishing gradually, as the temperature descended gradually below that of the atmosphere, until it reached the temperature of $18^{\circ}\cdot5$, which appears to be the lowest degree ever attained. The speed of the main shaft was, during the first-named experiment, twenty revolutions per minute, when the injected water

Siemens. was raised 3° , and the brine in the cistern reduced only 2° per hour at the commencement of operations, and during the second experiment the speed varied from fourteen to sixteen revolutions per minute, when the injection

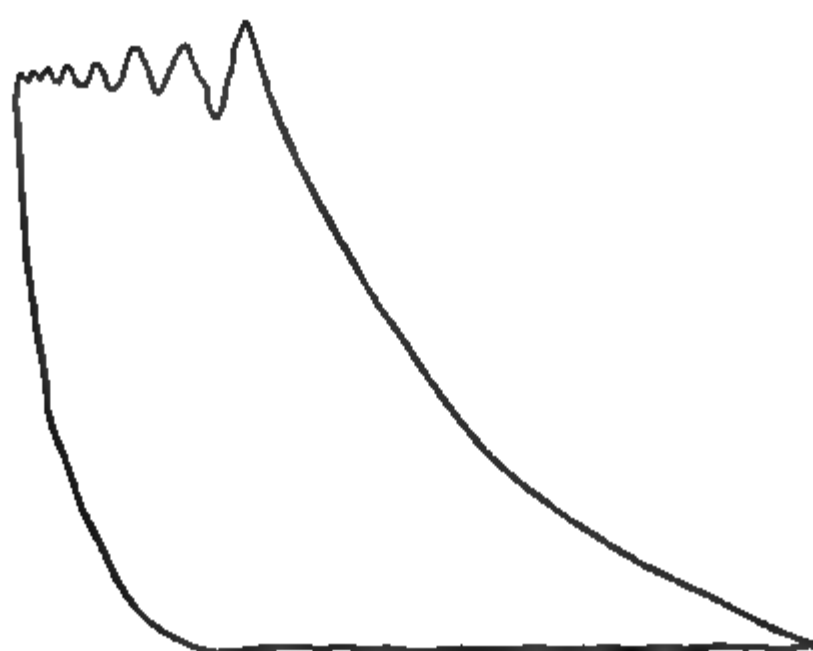


water was raised only $2\frac{1}{2}^{\circ}$, whereas the brine in the cistern was lowered 8° Fahrenheit per hour, until it had descended considerably below atmospheric temperature. The water to be frozen had been filled into cans of copper and dipped into the brine, after the greatest depression of temperature had been attained, which caused a rise of temperature from $18^{\circ}\cdot 5$ to 22° or 23° .

"When I examined the apparatus I found the speed to average fifteen revolutions per minute, and the following are the mean pressures and HP. indicated upon the three cylinders, viz. :—

	Mean Pressure.	HP.
The steam cylinder according to data obtained from Mr. Blake	8·8 lbs.	32
" Compressing cylinder (Fig. 2)	26·75 "	37·85
" Expanding cylinder (Figs. 3 and 4) with injection }	18·25 "	21·1
" " " without "	14·22 "	16·5

FIG. 2.



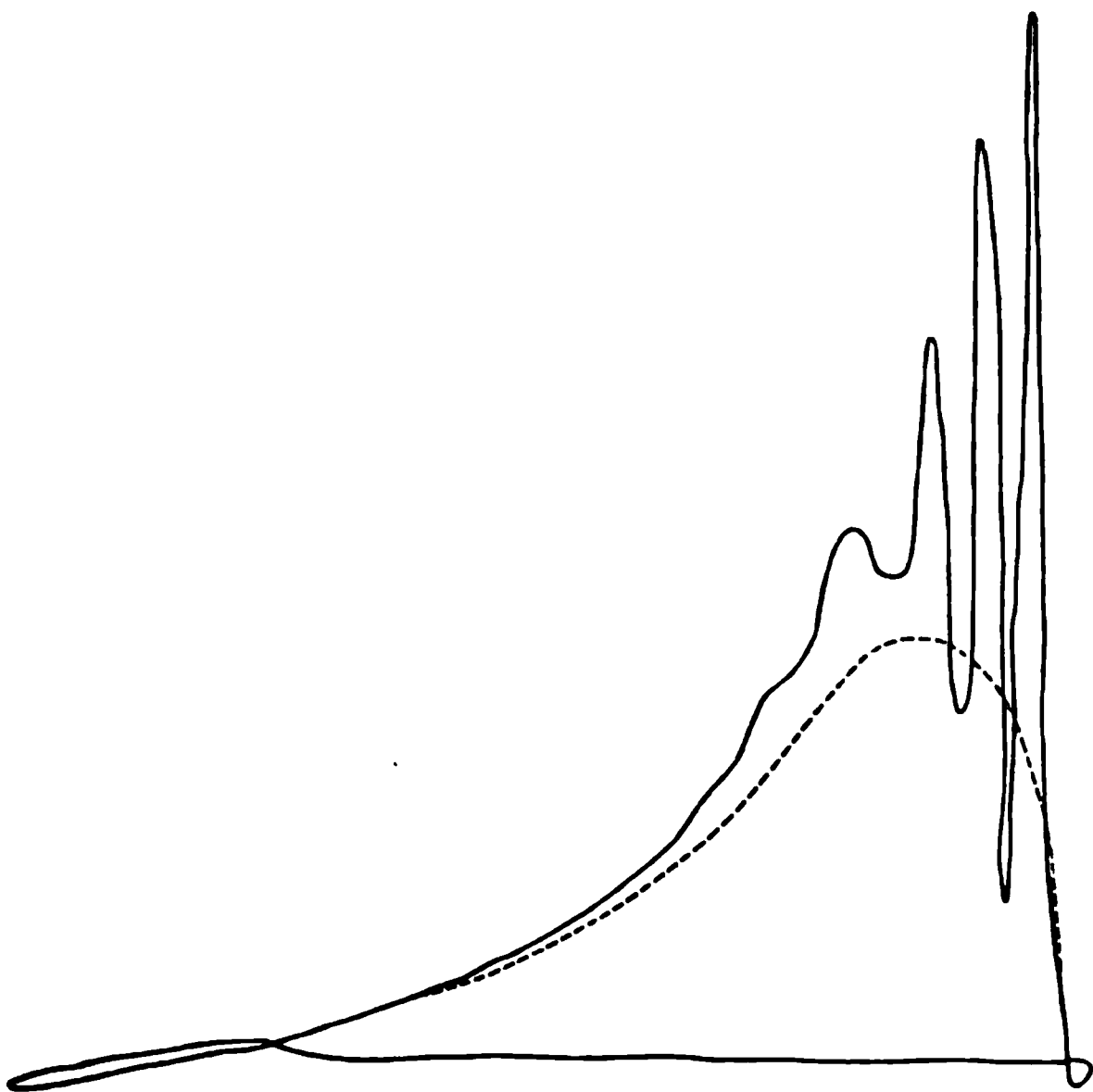
COMPRESSING CYLINDER.

Mean pressure 26·75 lbs., HP. 37·85.

"*Theory.*—Before entering into a consideration of the merits and defects of the apparatus in its actual condition, it will be of advantage to establish generally the principles whereon its effect depends. The heat which it is purposed to abstract from the water is communicated to expanding air, or, in the language of modern science, is converted into mechanical effect, and it can be proved philosophically that a caloric engine may be devised which derives its power from the latent heat of water in causing it to congeal. In fact, the heat communicated by the injected solution to the expanding air is a source of power to the machine, which would yield both effective power and ice but for the compressing cylinder, which in the arrangement described has to be worked by an engine. The power expended in compressing the air produces, however, its equivalent of heat, which heat would be sufficient, in a philosophically perfect arrangement, to reproduce the power necessarily expended by the engine, and a surplus of effective power proportionate to the heat abstracted from the water would be realised. This view of the principle involved in your

Siemens.

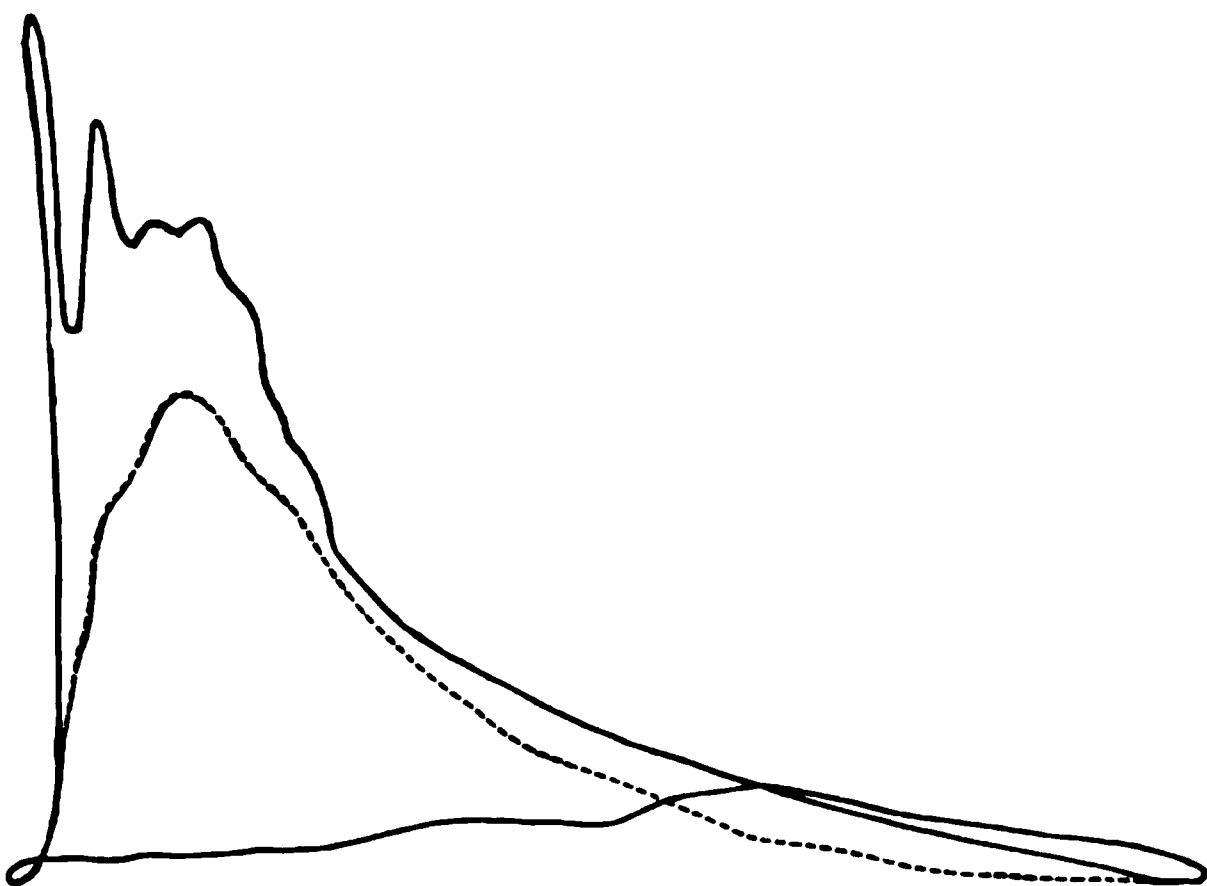
FIG. 3.



EXPANDING CYLINDER OFF SIDE.

Continuous line with injection mean pressure 19.00 lbs., HP. 22.0
Dotted „ without „ „ „ 14.75 „ HP. 17.1

FIG. 4.



EXPANDING CYLINDER NEAR CRANK.

Continuous line with injection mean pressure 17.50 lbs., HP. 20.3
Dotted „ without „ „ „ 13.70 „ HP. 15.9

machine is novel, I believe, and somewhat startling; but I am confident it will be acquiesced in by those conversant with the dynamic theory of heat, and although the conditions of the ideal machine will probably never be realised, it is important for our purpose to know that the production of ice does not necessarily involve an expenditure of power.

"Starting, then, with the admission that the heat produced in the compressing cylinder is practically unavoidable, the question arises, how great is the necessary expenditure of engine power, or, in other words, the difference between the power absorbed in the compressing cylinder and the power obtained in the expanding cylinder. This difference of power arises in consequence of the abstraction of heat from the compressed air, and is directly proportionate to the number of degrees of heat abstracted or generated in compression and afterwards lost in expansion. The quantity of heat lost in the expanding cylinder is, however, proportionate to the power produced in expansion, and is entirely independent of the limits of expansion which, as has just been shown, determines the degree or quality of cold produced. It follows that low rates of compression and expansion of the air are favourable to the production of cold with the least expenditure of engine power, and I find by calculation that the power value of a given amount of heat abstracted (or cold produced) increases in the ratio of the squares of the number of degrees of reduction of temperature required.

"It is therefore highly advantageous to compress and expand large volumes of air to a moderate extent, consistent with the requisite energy of action of the machine.

"Adhering for the present to the rate of compression obtained in working your apparatus, namely, 55 lbs. per square inch effective pressure, the following result might be obtained if no incidental losses of any kind were obtained, and taking the speed at fifteen revolutions per minute:—

HP. indicated in compressing cylinder.	35.0
" " expanding do.	25.2
" " engine	9.8
Units of heat produced in compression per minute . . .	1,500
Injection water raised in compressing cylinder . . .	2°·5
Units of heat produced in expansion	10.80
Ice produced per hour from water of 60°	381 lbs.
600 gallons of water cooled per hour	10°·8
The diameter of expanding cylinder to be	17½ inches

"In comparing these results with those actually obtained, it will be observed the compressing cylinder did its work remarkably well, whereas the duty obtained from the expanding cylinder falls manifestly short of the results indicated by theory. It was necessary then to inquire carefully into the causes operating against the performance of the expanding or freezing apparatus, and the following are the results of that inquiry:—

"1. The power developed in the expanding cylinder should be 25.2 HP., whereas only 16.5 HP. was actually indicated (when no solution was injected), owing to—

- "a. A great loss of pressure between the reservoir and the cylinder.
- "b. Excessive expansion beneath the atmospheric line, which involves a loss of power on the return stroke.
- "c. Imperfect adjustment of the admission valves.

"2. When solution was injected the indicated power rose to 21.15 HP., or 6.93 HP. higher than before, which excess of power may to a great extent be

Dr. Siemens. fictitious, being caused by the penetration of the solution into the indicator, but it proves that considerable force must be expended in forcing and agitating the solution, and all the power so spent will produce its equivalent of heat and must be deducted, besides the power lost in friction of piston, from the indicated 16·5 HP. in estimating the refrigerating effect to be produced.

“3. The compressed air being cooled by injection of cold water, it will certainly be saturated with vapour, which vapour will be condensed and converted into ice during expansion, and produce a white fog pervading the expanded air.

“The quantity of vapour so condensed and congealed, supposing the temperature of the compressed air in the reservoir to be 68° Fahrenheit, amounts to 0·06 lb. per minute, yielding about 1,330 units of heat, which represents a loss = 1·9 HP.

“4. The expanded air leaves the apparatus at the temperature of the cistern, or say at 20°, which is $68^{\circ} - 20^{\circ} = 48^{\circ}$ below the temperature at which it entered the compressing cylinder, which represents a loss of effect = 312 units = 7·25 HP. at the least.

“5. The cistern containing the solution, the expanding cylinder, the pump and the connecting pipes, present an aggregate surface of about 200 superficial feet of heat-absorbing surface $65^{\circ} - 20^{\circ} = 45^{\circ}$ cooler than the surrounding atmosphere on an ordinary summer's day. The machinery especially being ill-protected, and of a dark colour, I estimate the loss of effect from this source at about 3·6 HP., assuming that the covering prevents two-thirds of the radiation which would take place if the surface were unprotected. Assuming that the solution in the cistern has been reduced to 20° Fahrenheit, the total losses are as follows:—

By throttled passages, &c., see paragraph 1	.	.	.	10·08 HP.
„ agitation and friction	„	2	.	say 3·00 „
„ condensation of vapour	„	3	.	1·90 „
„ cold air leaving cistern	„	4	.	7·25 „
„ absorption of heat from the atmosphere	„	5	.	3·60 „
<hr/>				
Total loss	.	.	.	25·83 HP.
Total power to be obtained	.	.	.	25·2 „
<hr/>				

It follows that when the temperature of the cistern is reduced to 20°, the losses of cold produced equal or actually exceed the power of the apparatus of producing the same, which result is corroborated sufficiently well by the experience obtained, although it has been the result of independent calculation.

“As regards paragraphs 1, 3, and 4, and of approximate as regards paragraphs 2 and 5, which, however, are the less important.

“The next question is whether, and to what extent, these different sources of loss can be obviated; and I will at once proceed to describe the fresh arrangements I propose for your adoption, and which are illustrated by the accompanying sketch.

“The proposed expanding and freezing apparatus consist of a cylinder of cast iron of 17 inches diameter, instead of 19 inches, and 4 feet 6 inches stroke. The pipes and valves connected with this cylinder to have a sectional area of not less than 15 square inches (instead of 7 square inches), and no stop-valve to be introduced. The admission valves to cut off at one-fourth part of the stroke. The expanding cylinder is immersed in the cistern containing the freezing solution,

and the expanded air issues from the cylinder into chambers *a, a*, forming the inner sides of the cistern, which chambers are perforated towards the bottom to allow the air to bubble through the solution. The cistern to be about 10 feet long, by 5 feet broad, by 2 feet 6 inches deep. The expanded air issues from the cistern into the atmosphere through a series of vertical tubes contained in a cylindrical air-tight chamber (C), through which the compressed air circulates on its way to the cylinder. The compressed air enters the annular chamber through a pipe *b*, and issues into the tube chamber C, through a number of holes in order to distribute it uniformly. It then descends gradually, and effects an interchange of temperature with the expanded air within the tubes, which latter issues at the top at nearly the temperature of the compressed air on entering, whereas the compressed air reaches the expanding cylinder nearly at the temperature of the cold cistern or below the freezing-point. The annular chamber "*d*" serves to collect the cold compressed air at the bottom, and to supply it to the admission valves *e* and *f* by means of pipes not shown. The tube in the centre of the chamber C is of about 9 inches diameter, and contains a cylindrical vessel (*g*) filled with water, which enters the same from above, and is withdrawn at the bottom in a cooled condition to fill the former for the production of ice. The tube surface required is about 200 superficial feet.

"The advantages obtained by this exchange of temperatures are very important. The compressed air is reduced below freezing-point before it reaches the expanding cylinder, and the aqueous vapour it contained is at the same time condensed upon the tubes. Indeed the lower the temperature of the cistern descends the more will the compressed air be reduced in temperature, and the cold produced will accumulate in intensity to any desired degree. Both injection pumps and one of the large air receivers may be dispensed with, for it makes no difference at what temperature the compressed air enters the exchanging apparatus. I should recommend, however, to retain the injection pump of the compressing cylinder till the efficacy of the new apparatus has been proved by experiment.

"This new apparatus would reduce the different losses of refrigerating effect in the following proportions, according to my estimation, viz. :—

Probable loss expressed in HP.

1. By throttled air passages, say	2.5 HP.
2. " Agitation and friction of piston	1.5 "
3. " Condensation of vapour in expanding cylinder	0.5 "
4. " Cold air escaping	2.5 "
5. " Heat absorbed by radiation.	2.0 "
	<hr/>
	9.0 "
Gross power of expansion	25.2 "
	<hr/>
Leaves effective refrigerating power	16.2 "

which is capable of producing 258 lbs. of ice per hour.

"The production of ice may, however, be increased 25 per cent. in working the apparatus at the rate of twenty revolutions per minute, which the increased passages, &c., admit of. It is hardly necessary to draw your attention to the gain of engine power which the proposed alterations are calculated to effect. In order to reduce the engine power required to its proper limit I should propose considerable modifications in the general arrangement of the apparatus, consisting chiefly in attaching the three pistons upon one rod, in accelerating the speed of the pistons, and in compressing the air to only about 80 lbs. per square inch.

Dr. Siemens. “*Cost.*—An apparatus so constructed would be considerably less complicated and costly than our present apparatus. The expanding cylinder might be made of cast iron, the two injection pumps and one air reservoir would be suppressed, and in their stead the comparatively cheap exchanger of temperatures or reciprocator be added. The engine and moving gear would, moreover, be greatly diminished. The proposed alterations in the existing apparatus would not cost above £200 (I consider), taking into account the value of materials of the present expanding cylinder and injection pumps.—London, 28th July, 1857.

“(Signed) C. W. SIEMENS.

“To Wollaston Blake, Esq., F.R.S., &c.”

Mr. Thomson. Mr. DAVID THOMSON said he had been much interested in the Paper, the theoretical part of which he thought was quite correct. Dr. Siemens had thrown some doubt upon the formula as given in the Paper, p. 147; Mr. Thomson had the honour of laying this formula before the Institution some years ago, when Mr. Kirk’s Paper on the Mechanical Production of Cold was read and discussed.¹ At that time Dr. Siemens mentioned that the formula was due to Clausius, but Mr. Thomson had deduced it from Rankine’s works.

Dr. Siemens. Dr. SIEMENS observed that Clausius and Rankine worked independently and simultaneously at the same question, and arrived at the same conclusion. He did not doubt the correctness of the formula put forward by those eminent mathematicians and physicists, but he doubted its applicability under all conceivable circumstances to the question under consideration.

Mr. Thomson. Mr. DAVID THOMSON replied that if the formula were not applicable to that question it could hardly be applicable to any other, because it was professedly to give the ratio of power required to produce a certain amount of cooling effect depending upon the difference of temperature between the hot end and the cold one of the cooling machine. For himself, he thought the formula was correct, and it had been adopted in the Paper as the foundation of the theory applied by the Author. Although the Author had laid great stress upon the point, that a certain amount of cooling effect per HP. was obtained, that was not stating the whole question, because the power required for any given amount of cooling work depended very much upon the lower temperature. It would require a great deal more power to produce a certain amount of cooling effect if the temperature was to be much reduced. He wished to ask the Author how it was, that in his extensive practice, he had been in the habit of cooling the air so much more than was really required according to his own statement. The room in which the meat was preserved and brought

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 295.

from Australia had been usually reduced to about 25° Fahrenheit; Mr. Thomson but in his machine, according to the statement in the Paper, the usual temperature of the air when it was discharged was no less than 70° below zero Fahrenheit. Mr. Thomson had made a short calculation showing that that reduction would necessarily cause the theoretical power required to be increased by three or four times what it would be if the air had been only reduced to 10° Fahrenheit. He thought it would have been better if the Author had been contented with a much more moderate degree of cold, and had increased the size of the air-cylinders and the quantity of air manipulated; the extra cost involved would only have been that of making the diameter of the air-cylinders a few inches larger, which would have been a very small item indeed. The Author had given a calculation of the power exercised upon the air in order to cool it, but that calculation appeared to him to leave out of account entirely the cooling that the air underwent in its passage between the two cylinders—between its compression and its expansion. It was there made to pass through pipes exposed to the cold air already produced, and it underwent a certain amount of cooling, which was for the purpose, as stated by the Author, of taking part of the water out of the air and causing it to condense, which he had no doubt was proper, but he thought in being thus cooled, that the air escaping from the cold chamber to re-enter the cooling machine was heated to the same extent that the air in the pipes was cooled, and therefore that such cooling effect could not be included in the useful work done, and ought to be deducted in estimating the cooling work effected by the machine. He should be glad to know from the Author at what temperature the air escaped from the compression cylinder into these cooling pipes, and also from the cooling pipes into the expansion cylinder; also at what temperature the air that had passed through the refrigerating chamber returned to the machine to be once more operated upon. All these elements must be taken into account in order to ascertain the real cooling power of the machine. Without such information it was impossible to ascertain exactly its economical effect.

Mr. W. SCHÖNHEYDER remarked that the Author had given some very valuable information about the work done by his own refrigerating machines and others for bringing meat in good condition from long distances; but engineers were apt to be inquisitive, and he wished to know a little more about the machines that had been described. It would be interesting if the Author would add to the diagrams the hyperbolic compression-curve; it could then be

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seen what amount of heat was abstracted in the cylinder, and what was left to be abstracted by the shower of rain in the towers. It would also be interesting if he would add to the expansion diagrams the theoretical expansion curve, that it might be compared with the curve obtained. He should like to know also the amount of water used for cooling the air, the initial temperature, and the final temperature. There were a few particulars given in the Paper, but only in a very scattered way. If the Author would supply the results of one complete set of experiments, with those data, it would be a valuable addition to the Paper. With regard to the formula on p. 147, he agreed with Dr. Siemens that though correct in itself it was not applicable to the case under consideration, because it was not a question of converting work into heat, or, in other words, converting work into abstracting heat, but of simply taking heat out of meat and putting it into water. To use a simple comparison, if a train weighing 100 tons was moved 100 feet horizontally, it was not necessarily doing any work; it was simply moving the train from one spot to another, and theoretically there would not be consumed any power in doing it; but there was frictional resistance, the resistance of the atmosphere, and so on, and therefore power must be consumed. If, however, the train were lifted 100 feet power must necessarily be consumed. In like manner to convert mechanical power into heat, or (if permissible to say so) of converting it into cold, it was simply taking the heat out of the meat and putting it into the water; unfortunately, however (as in the other case), "frictional" resistance was encountered, and would therefore consume a certain amount of power, but not anything like in proportion to the theoretical power obtained by calculating according to Joule's equivalent of 772 foot-lbs. per heat-unit. As a proof of that he would refer to the work done by some of the best refrigerating machines; for example, that which he considered the best and most economical, Reece's, and it would be found that in cooling water to a moderate degree as much as 6,000 units of heat could be abstracted per lb. of coal, which was not far from the theoretical duty to be got out of 1 lb. of coal. The whole theoretical duty was 14,000 units, but, using coal under a boiler, it was not much more than 8,000 or 9,000 units; with the machine in question, in spite of the losses due to a machine of that kind, it was 6,000 units. He considered the machines that had been described valuable for their particular purpose, for use on board ship, on account of their convenience, and the absence of chemicals, but he

dissented from the Author when he wished to recommend them for all purposes, because there could be no doubt that they were uneconomical for abstracting heat. The amount of heat they could extract in proportion to others was not much more than one-half or one-third. With one of Siddeley's best machines, or one of Reece's, 1,600 units of heat could be abstracted per lb. of coal in making ice, or passing through a range of say, 170° . In the cold-air machines not much more than 600 or 700 units could be abstracted. The Author had spoken of the accumulation of ice on the pipes to the extent of several inches. When meat was first brought from America it was well known that there were two qualities in the market, one which was wet and flabby, and did not last long, and another which was in a good dry condition, and kept a long time. The first was kept in a chamber cooled by passing a current of air over ice, so that it took up a large amount of moisture from it; while the second was kept in a chamber cooled by a system of pipes arranged at the side of the chamber, through which cold brine was circulated. He remembered examining one of the steamers on its return from America. The meat was in excellent condition, and the pipes in the chamber were covered with hoar-frost, not 2 inches thick, but only $\frac{1}{4}$ inch thick, which had accumulated during the voyage. He thought that the great advantage of the system, if it could be used on board ship, would be, that the moisture in the atmosphere, and that derived from evaporation from the meat, which always took place, would be congealed on the pipes, and the atmosphere would always be dry. When meat was hung for preserving, it was always housed in a dry place, and it was sometimes necessary to wipe the damp off, in order that it might be well preserved. He could not concur with the statement of the Author that it was much more difficult to cool solid meat than to freeze water. He agreed, however, that the friction of the pistons in the expansion cylinder was a drawback to the machine. Not only was extra power consumed, but the heat generated counteracted the cooling effect sought to be produced. The Author had referred to some calculation of Rankine and others as to the cooling effect produced—as much as 13,000 units per indicated HP. Of course at present it was not one-tenth part of that, owing to the unavoidable losses. The Author had alluded to the capacity of the meat chambers; and had said, that a certain size of machine was necessary for meat chambers of a certain capacity. No doubt it was convenient for shipowners; but engineers ought to bear in mind that the amount of cooling effect did not depend exactly upon the capacity of the chamber, but

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Mr. Schönheyder. upon the surface of the chamber. There was a certain amount of heat constantly permeating through the walls of the chamber: but that amount depended upon the surface of the walls, and not upon the capacity of the chamber. He knew from experience in heating buildings, that the amount of heat which was lost from rooms depended upon the surface, and not upon the cubic capacity. Reference had been made by the Author to the machine supplied by his firm for New South Wales, and he had given the units of heat abstracted in twenty-four hours, or rather the amount of work which the machine was capable of doing, and also the amount of meat to be cooled. The cooling power of the machine was about double the cooling power necessary to extract the amount of heat from the meat. Perhaps the Author would say whether that double amount was really necessary for keeping the room itself cool. And it would be interesting if he would give the dimensions of the room, and state what the walls were made of. It seemed a very low efficiency if double power had to be employed simply for the sake of keeping the room cool. The Author had stated that he was in the habit of calculating his machines as equivalent to producing so much ice in a given time. That might be a convenient way, but it was rather deceptive, because, calculating from the amount of heat which the machine might extract, the production of ice would appear excessive. The Author had spoken of machines that produced 5 lbs. of ice per lb. of coal, but Mr. Schönheyder doubted if any cold-air machine had ever produced such an amount. Even if it had produced as much as 2 or 3 lbs., that was only a small fraction of what other machines could do, such as Reece's, or the ether machine. Reference had been made to the possibility of the cold-air machines being equal in economy to the ether and ammonia machines, but he thought that impossible, for the reasons he had stated.

Mr. Lightfoot. Mr. T. B. LIGHTFOOT said the Author had stated certain conclusions, to which he had been led by an attentive consideration of the matter upon general principles. The third conclusion was that "direct injection is the quickest and most effective method of cooling air to the temperature of the water, which is a condition necessary to the working of a machine with the least expenditure of power." That no doubt was true so far as it went, but the Author had omitted to state that in cooling with injection, the quantity of water used was so enormous, that when it had to be paid for, the cost was so great as absolutely to preclude the use of air-refrigerating machines, unless some other cheaper and equally efficient system could be employed. He might be permitted to

cite a case he had in hand, in which air-refrigerating machines Mr. Lightfoot capable of delivering 80,000 cubic feet of cold air per hour were required. To accomplish that with surface cooling, water equal in weight to twice the weight of air, or 1,600 gallons per hour, would be sufficient, while if injection were adopted no less than 8,000 gallons would be required. Taking the case given by the Author in which the quantity was stated to be equivalent to twenty times the weight of air, the amount of water would then be no less than 16,000 gallons per hour. In the case in question the cost of the water would be 1s. 3d. per 1,000 gallons; calculating that out, there would be, on the one hand, a yearly expenditure of £880 with surface cooling, and on the other hand, even adopting his low estimate for injection, a yearly expenditure of £4,400, showing a difference of about £3,500. There would be a saving of coal from the compression being accomplished in a more economical manner with injection, but as the cost of the total amount of coal used by the machines only came to £1,500 a-year, including what would be required for working electric-light engines, lifts, and other mechanical appliances, any little saving there would hardly affect the question. The reason of course was obvious. Good coolers raised the water from 30° to 40° without any special appliance, while with injection the air must take the same temperature as the final temperature of the water, so that the water could only be raised some 5°, and of course the quantities used were in inverse ratio of the number of degrees by which the water was raised. At sea the case was different, and sometimes also on land, where cooling tanks could be employed. He could not agree with Mr. Haslam's remark, with reference to injection, that as the air was increased in temperature to 300° by compression, it would absorb an immense quantity of water, and give rise to large amounts of snow after expansion. That was not the case, because with the injection of water the compression was accomplished almost isothermally; the temperature of the air rose little above that of the water, and of course as the amount of moisture contained in solution by a given volume of air was merely a function of the temperature, the quantity was unaltered, whether the cooling was effected by injection or surface contact. It was to be regretted that the Author had not given any details as to the effect of his drying pipes. He had stated his conclusion that the most convenient way of liquefying vapour was by the method which he had adopted, but throughout the Paper and the diagrams and tables no reference was made to the effect of the pipes, and Mr. Lightfoot was very sceptical as to their value.

Mr. Lightfoot. The Author should give extracts from logs or other papers, showing how much the air was reduced in temperature by the drying pipes, and what was the condensation and deposition of moisture. He thought also that there should be some explanation as to the very large ratio adopted between the capacity of the compressor and the capacity of the expander, which appeared to be in no case less than 2 to 1. As the reduction in volume due to temperature, even taking the worst case that could occur in the tropics, was only 1·4 to 1, it appeared to him that there must be a great loss of efficiency in the Author's machines. Mr. Lightfoot had never adopted a greater ratio than 1·8 to 1 even in the smallest refrigerators, while in those delivering 15,000 cubic feet of air per hour and upwards, he had found that a ratio of 1·6 to 1, and 1·5 to 1, gave exceedingly good results, even keeping in view that the terminal pressure, after expansion, must always be a little above that of the atmosphere in order to get a proper exhaust. With regard to the diagrams, he agreed with Mr. Schönheyder, that it was a great pity the Author had not given more details; because it was impossible to ascertain from the mere inspection of the figures what was the efficiency of the machines. There was not even a vertical scale to show the pressures. The most remarkable statement in the Paper appeared to him to be that which referred to the enormous amount of steam power required for working the Author's machines. He alluded especially to the particulars given of some refrigerators at Messrs. Denny and Sons' works in Ireland. The HP. was stated at 68, and the revolutions seventy per minute. He had calculated from the particulars given, the theoretical amount of power involved by the abstraction of heat, or the actual loss of heat energy, and he had ascertained that it could not be more than 40 HP. assuming the compression to be adiabatic, and the expansion also adiabatic. Of course, as the Author used injection, compression with his machine should be nearer the isothermal line, and the HP. should therefore be considerably below 40. From Mr. Lightfoot's experience, he should never think of allowing more than 50 or 55 HP. for a machine of that capacity. A machine made by him for delivering 15,000 cubic feet of cold air per hour, and working with close approximation to adiabatic compression, only took some 26 indicated HP.; and he thought that Messrs. Hall and other makers of refrigerating machines would bear him out in stating that that was a most ample allowance. His results, therefore, as to efficiency were at variance with those of the Author, and he should consider that he

was doing exceedingly bad work if his compressors only gave Mr. Lightfoot 70 per cent. of discharge, which the Author took as his basis. Instead of getting 50 per cent. back from the expansion cylinder, as the Author had stated, he had actually got from 60 to 65 per cent. with almost adiabatic compression, and he calculated that the Author should obtain at least 70 per cent. if his machines were doing proper duty. The Author had mentioned a system introduced by Mr. Lightfoot for abstracting moisture, but his description of the apparatus was not correct. He did not employ two expansion cylinders, as stated in the Paper, but one, with a trunk piston, and there were no more working parts in his machine than in the Author's. The moisture was condensed and deposited without the use of external drying pipes, as in the Author's system, by merely partially expanding the compressed air in the first instance to such degree that the temperature was reduced to 35° or 40° Fahrenheit. The result was the condensation of almost the whole of the contained vapour, which was discharged in the form of mist with the partially expanded air into a small vessel, either placed alongside the machine, or combined with the bed, and having surfaces so arranged that the air in passing through was entirely deprived of its suspended moisture, which fell to the bottom of the vessel, and was automatically drained off. The air thus dried was then finally expanded down to atmospheric pressure, and discharged cooled and practically free from snow. The primary expansion was accomplished in the annulus formed by the trunk, the grade of cut-off being regulated according to the temperature of the cooling water, and the final expansion was carried out behind the full area of the piston. The same degree of dryness could be obtained in the tropics as in colder climates, and the temperature of the cold air was kept constant under all variations in temperature of the cooling water. He might mention that under extreme conditions of tropical heat he could recover 94 per cent. of the water entering, the remaining 6 per cent. being left partly in solution in the air and partly discharged as snow. He did not think the Author's opinions on ventilation would be largely adopted; indeed, he thought few people would like to have air coming into their rooms at a temperature of 50° below zero; nor did he believe that to be a correct method of ventilation. It was generally admitted that the best method of ventilation was to introduce large quantities of air at a comparatively high temperature.

Mr. JOHN IMRAY had been consulted as to what air refrigerating Mr. Imray. machines ought to be employed on board ships and steamers. He

Mr. Imray. had looked carefully into the different machines—the ammonia, the ether, the sulphurous acid, and the air refrigerating machines, and he had no doubt that what might be called the chemical machines were on the whole the most economical; but there were serious objections to their use on board ship. It was found improper to have on board ships such substances as ammonia, sulphurous acid, or ether. The chance of leakage or escape, the difficulty of handling the reservoirs, and other things, were very serious, and therefore it was necessary to have recourse to simple compression and expansion of air as a means of producing cold, giving up a certain amount of economy. In his experience of air refrigerating machines, there had been no practical mechanical difficulty except one, the choking of passages by ice and snow. The machines could not be worked unless very great precautions were taken, without having the passages so choked; he therefore thought that any one studying the question should direct attention principally, as Mr. Lightfoot had done, to divesting the air of moisture, not only to save the power which was lost by the condensation and freezing of the moisture, but also to save the stoppage of the machine, which was sure to occur from the blocking of the passages. The Author had adopted one method in cooling air which appeared to Mr. Imray to be utterly fallacious. If the air to be dealt with were already saturated with moisture there could perhaps be no harm in cooling by injection of water or by a shower of water, on the principle that one could not fill a bottle with more than it could hold. But that was not the problem. The air, which was usually not nearly saturated when it was put into the pump, had more water added to it, which saturated it. The air came from the cold chamber, where there was very little moisture to begin with. Why should moisture be added which had afterwards to be removed? He might mention some experiments which he had made with air refrigerating machines to show that he was right in his view. Considerable difficulties were at first experienced from the choking of the passages with ice and snow. They were able to work in the ordinary way about four or five hours, when they were choked and stopped. He next passed the air before it reached the compressing pump over some trays of chloride of calcium to take the moisture out of it, and then, instead of going for four or five hours, they went for twenty-four. That showed how important it was to remove as much moisture as possible from the air to begin with. Every particle of moisture that had to be cooled and condensed was a source of so much power thrown away, besides much risk of stopping the

machine. If engineers would direct their attention to finding an Mr. Imray. easy and convenient means of removing moisture from the air dealt with, he was sure they would be on the right track.

Mr. JOSEPH BERNAYS wished to direct attention to the principal Mr. Bernays distinction that appeared to him to exist between the Author's machine and others—the secondary cooling by means of pipes specially prepared for the purpose, such as had been proposed years ago by Dr. Siemens. The object of the cooling at that part of the process would appear to be not so much the lowering of temperature as the extraction of water. The few degrees of heat that were abstracted through the pipes would not be sufficient to add greatly to the efficiency of the machine; the object was simply to precipitate the vapour, or some of it. He wished to ask the Author, and those who had been connected with the subject, whether chemicals had ever been used to absorb the water at that stage; various substances might be used for the purpose, such as quicklime, which would take up vapour very quickly. It appeared to him that the cylinders and the whole arrangement as explained answered perfectly well, and were constructed in a proper manner. To avoid friction great strength of parts, and very careful working and fitting, were of primary importance in air-compressing machinery. He had constructed air pumps for compressing air to 150 lbs. to the square inch, which worked up to 220 lbs. on trial, and a still higher pressure could have been attained, but at a risk of breaking the machine, which was not constructed for such a high pressure. By merely altering the outside pipes, shutting some valves and opening others, the pump was changed into an air-exhausting pump, without any alteration in the machinery itself. The valves and pistons were constructed very much like those shown by the Author.

Mr. J. K. KILBOURN observed that the best method of cooling Mr. Kilbourn compressed air was an open question. The Author started with injection in and out of the cylinder, and until now he had made no change, and the record he had given showed satisfactory results. The main objection to that method of cooling raised by Mr. Haslam was not tenable. True, air at a high temperature had an increased capacity for moisture; but, on the other hand, that capacity was diminished in a direct ratio with the degree of compression. A cubic foot of air at normal pressure and a temperature of 100° Fahrenheit, would hold 20 grs. of aqueous vapour. Compress that air to 4 atmospheres absolute, and it would hold only 5 grs., and even that amount uniformly decreased with every reduction of temperature. To dry the air while under com-

Mr. Kilbourn. pression there must be a surface (preferably of metal) upon which to deposit the vapour in excess of saturation, and whatever water there might be in mechanical suspension: that surface was provided by the Author in his drying pipes. The point raised that an excess of water in the cylinders, and especially salt water, had a detrimental action on the cylinders and valves, had more force, and was worthy of consideration; but experience was the best teacher, and he would ask the Author for more explicit information upon that point. For instance, what was the present condition of the compression cylinders of the machines longest in use? Had he found occasion to rebore them? and how often? Did the valves fail from the corrosive action of the salt water? Or did they literally wear out? Injection in and out of the cylinder was efficient, and doubtless the cheapest method known; but the vital point to be determined was whether the advantages more than counterbalanced the disadvantages. An economical expenditure of force lay in the direction of rapid cooling within the cylinder, and if a cylinder with "properly constructed jackets" showed any marked advantages in that respect, it would, he trusted, be clearly shown. That a "cold-air machine" was the most convenient method for cooling preserving chambers no one could question; but he could not so readily follow the Author's views either as to the working or comparative efficiency of machines producing cold by the evaporation of volatile liquids. With all these liquids, as with air, where low temperatures were required, as in ice-making, the intervening range between the temperature of the cooling or condensing medium and the freezing-point might be counted as practically nil. That loss, with an ammonia machine and condensing water at a temperature of 60° , would be about 5 per cent. of the total cooling power. With ether under similar conditions the loss would be 14.5 per cent., while with a cold-air machine, discharging air at 50° below zero, the loss would be 33 per cent. A "chemical" machine working at fixed pressures should be equally efficient at all temperatures above the boiling-point of the volatile liquid minus the loss previously referred to. In making steam (and the process was quite analogous) slow combustion required extended fire-surface. So in the present case, if the saline solution which furnished the heat had a return temperature approaching that of the vaporizing liquid, the contact-surface between the two liquids must be sufficient to furnish the heat essential to vaporization. Cooling a chamber with ice was somewhat different from cooling it through ice. The frost-work covering of a brine-pipe would partake of the temperature of the brine within the pipe, and

would transmit a degree of cold proportionate to that of the brine Mr. Kilbourn which produced it and not necessarily that of the "melting-point of ice." As to efficiency, the ice equivalent of actual production as stated by the Author was not more than 60 per cent. of the theoretical possibility of a cold-air machine; but in point of efficiency, a cold-air machine working theoretically perfect would not compare favourably with machines using the condensable gases. Careful calculations, based upon the theoretical production of cold with a given weight of steam, showed that, taking air as the unit, ether was 2·25; ammonia by absorption, 4·6; ammonia by compression, 7·7. Notwithstanding the low efficiency of the cold-air machine it had won a foremost position in public favour. It acted direct, without any intervening medium to transmit the cold, required no chemicals, and was easily understood. On ship and in some places on land there was no apparent likelihood of its being displaced by any machines yet brought out.

Mr. E. A. COWPER said that reference had been made to Professor Mr. Cowper. Piazzi Smyth, who, in 1839, had worked with the idea of expanding air through loaded valves. The system of wire-drawing air through valves was certainly erroneous, if it was used with the idea of producing cold. But in any discussion on the means of producing cold, or the abstraction of heat from bodies or from air, the successful efforts of Jacob Perkins should be named, as it was he who first proposed, in 1834, the evaporation of a volatile liquid in a vacuum to produce intense cold. His first efforts were with "Caoutchoucine," a volatile spirit distilled from indiarubber. This was about the time that he took such an interest in the Adelaide Gallery, just then built. He well remembered Sir Frederick Bramwell telling him of his working at the apparatus at Mr. John Hague's, with a man of the name of Bell, since dead, and their succeeding, late at night, in getting a piece of ice in a cup, wrapping it in flannel, and hastening to Perkins' house with it in a cab, to the great delight of the old man. The "Caoutchoucine" smelt abominably, but ether was soon substituted for it, and answered better. He thought the experiment was worthy of mention, as being the first case of obtaining ice mechanically. It was somewhat astonishing, at the present day, that no advantage was taken in early times of the knowledge that by quick compression air was highly heated (indeed so heated as to render it capable of lighting tinder), it seemed now that it would have been so simple an idea to abstract that heat by "cooling water," and then let the air expand again without that heat, and so produce a very low temperature. Great credit was due to Sir John Herschel, for the idea of

Mr. Cowper. obtaining cold by the expansion of air, and it was unfortunate that the labours of Professor Piazzi Smyth and Dr. Gorrie were not better directed in the first instance; but the inquiries and experiments of Dr. Joule, Sir W. Thomson, and Professor Rankine, seemed to have done much to put matters on a sounder footing by the year 1856. In 1847 or 1848 Dr. Siemens made an experiment in Birmingham in which he assisted, and in which 30 or 40 lbs. weight of steam was expanded without producing work otherwise than by friction. The apparatus consisted of a small tin cylinder thoroughly protected so as to avoid radiation as much as possible, and they found that when the steam had no work taken out of it, the mere friction through the small aperture increased the temperature several degrees, showing that work was done in superheating steam. That was similar to the blowing of air through the loaded valves adopted by Professor Smyth, who, he had no doubt, did not get an efficient result. He thought the introduction of water as injection into the cylinder of compressed-air machines must be wrong in principle and in theory. It was almost the same as though it were wished to reduce the pressure of the steam in a boiler; and instead of having simply steam in the boiler, and opening a cock and letting the steam out, there was hot water at the bottom of the boiler. Then, instead of the boiler emptying of steam, there would be more steam made from the water at the bottom of the boiler. Engineers understood that well enough when they were dealing with hot water and steam; why should they not understand it as well when they dealt with water at the bottom of a vessel containing air? They attempted to cool the air by expanding it and allowing it to pass out. What took place? First, the air went out, and immediately following it there was a quantity of steam evaporated from the water in the bottom of the vessel, thereby neutralizing the effect of the expansion of the air to some extent, which if left to itself would produce a much greater abstraction of heat. He thought it was entirely wrong to introduce injection into the cylinder of a compressed-air machine. In the experiment at Camden Town, to which reference had been made, they worked day after day and week after week and wondered why they did not get a greater diminution of heat. First of all, as Dr. Siemens had explained, they wire-drew the air through the passages, and so they prevented the air doing its proper work; they also had a quantity of water in the cylinder, which moistened the air and injured the effect of the expansion. If water was not in the cylinder, and if the air was reasonably dry, the full effect of the expansion of the air was ob-

tained. He quite agreed with Dr. Siemens, that theoretically, if Mr. Cowper. actual power was not produced from the machine, but that a loss of heat only was sustained, it was certain that there had not been theoretically an expenditure of power, and an expenditure of heat in producing the result. There were frictions, and radiations, and imperfect conductions between the surfaces, and power was required for overcoming these losses and frictions; but that power was required to produce a loss of heat he denied. To produce heat there must be power, or to produce power there must be heat. As Mr. Schönheyder had said, there was no theoretical loss in shifting so many lbs. horizontally from one place to another; and so much heat taken from one place and put into another was not a loss of heat or a loss of power. Dr. Siemens had clearly stated that if the exchanger or regenerator (the instrument in which the temperature of the outgoing cold air was changed with the incoming compressed air) were carried out in a thorough manner, there would be very little loss, and very little power would be required to work the machine. It depended much upon whether the cold air passing out from a cooling chamber was wasted. Of course it was clear that the cold air took up a certain quantity of heat from the walls of the chamber, but when it was brought into close contact with the compressed air to cool it, such air deposited a good deal of its moisture. As had been pointed out in Dr. Siemens's early report in reference to the machine of which he had spoken,—“The compressed air is reduced below freezing point before it reaches the expanding cylinder, and the aqueous vapour it contained is at the same time condensed upon the tubes. Indeed the lower the temperature of the cistern descends, the more will the compressed air be reduced in temperature, and the cold produced will accumulate in intensity to any desired degree.” He therefore agreed with Dr. Siemens that in theory it was right not to introduce water into the cylinder, that it was right to keep the air dry, and that it was right to cool the compressed air as much as possible before beginning to expand it.

Sir WILLIAM ARMSTRONG, President, said Mr. Cowper was no Sir William doubt familiar with the fact that, when a small air-cock was Armstrong. opened in an air-vessel where there was a high compression, moisture would come out in a frozen state. He did not in the least degree question the correctness of the theory stated by Mr. Cowper, but he felt a little difficulty in understanding why the refrigeration was produced without any working being exerted.

Mr. E. A. COWPER said that in that case the air had been com- Mr. Cowper pressed to a high degree and cooled in a receiver, probably the air-

Mr. Cowper. vessel of a pumping engine, and when it was allowed to expand, it came down to a much lower temperature than it had in the first instance, though not so low as though it had done work in moving a piston, the work it had done being merely the pushing of the surrounding air away.

Dr. Siemens. Dr. C. W. SIEMENS said it seemed certainly contradictory that when air issued from a receiver into which it had been compressed it should actually produce particles of ice, and yet that no reduction of temperature should result from the expansion; but the seeming anomaly would vanish if the expanded air was allowed to collect in a receiver in open communication with the atmosphere.

Mr. Goodwin. Mr. G. A. GOODWIN thought that the question might well be considered under the following heads:—First, dryness and purity of the air; secondly, economy; thirdly, simplicity; and, fourthly and fifthly, space and cost. With regard to the dryness of the air, he had seen several ships, running between England and Australia, fitted with refrigerating chambers, in which meat was kept frozen below 32°, worked by the Bell-Coleman machine and others, and in every case the chambers and the carcasses were covered with a great deposition of snow. He thought that showed conclusively that the air was not dry enough for its purpose. One explanation would be that in the Bell-Coleman process the compressed air in the cooling pipes in the chamber, being hotter than the surrounding air in the chamber, would contain a greater amount of aqueous vapour than that in the chamber. To bring this compressed air to the best state for the deposition of moisture, it would have to be reduced to freezing point, and as it contained more moisture than the external air, for every degree of temperature 1 lb. of compressed air was lowered, 1 lb. of the external, air would have to be heated in a much larger proportion; therefore the air from the chamber that was drawn away and passed round the pipes, would have to be considerably under freezing point. This, he thought, would tend to reduce the efficiency of the chamber, although, perhaps, as Dr. Siemens had said, it might give future high results in the actual working of the machine. In machines which cooled the compressed air on its way to the expansion cylinder by the cold air taken direct from the machine, the efficiency of the machine itself was of course reduced, for if the air passed on to the chamber, it would increase the temperature of the issuing air in the chamber, and therefore not give such good results. The Author's method of injection would certainly reduce the power to deliver a given weight of air from the compression cylinder, but against that there were two things to set off. There was first the

wear and tear caused by the action of the salt water on the working apparatus; but, as a practical man, he did not consider that of much importance. The real defect was that possibly the machine might be worked where no fresh water could be obtained; in fact, the water might actually be foul, in which case the whole of the air passing through the machine would be contaminated, and very serious results might happen in a hygienic and mercantile point of view. He thought, therefore, that it would be best to discard water injection and adopt some other method. He observed that the diagram of the expansion cylinder indicated a great amount of compression. He thought that was bad in itself; it would increase the working pressure of the machine and so increase the wear and tear. To obviate that pressure, the ratio of expansion would have to be diminished, which would lead to a less amount of cold being obtained. If the remarks he had made were well founded, the Author's machine could not be a very economical one. As to simplicity, he was of opinion that no machine made to cool air by water injection on its way to the expansion cylinder could be a very simple one on account of the number of pipes and valves required. The questions of price and space occupied were not matters that could be well referred to, but he simply mentioned them to show in what order they should be considered. On board ship, space was of the greatest importance; on land, price would have to be considered. Looking at the whole question from a general point of view, he thought the best machine was one that would first cool the air by surface condensation only, on the principle of the surface condenser; long strokes ought to be adopted so as to reduce the proportion of the clearance to length of stroke to a minimum. Automatic valves were an advantage in reducing the number of moving parts, and ought to be as few as possible compatible with efficiency. If guides and other rods could be dispensed with a great deal of friction would be saved. All stoppages caused by accumulation of snow and ice could be done away with if separate orifices were made for the exit of the snow. Of course, the machine ought to be cheap and occupy a small space. He understood the Author to state that the difference in the combined energies of different cylinders was lost as friction. That was erroneous, as most of that lost energy would reappear in the heated waste air from the chamber, and in the cooling water.

Mr. H. W. NEILD said the Author had spoken of cooling chambers by means of brine pipes, and had stated that the ice on the pipes, after a time, would melt. He had not found that to be the case in his own experience. In a chamber at a factory in Bristol the brine

Mr. Neild. was reduced to a temperature of 25° below zero, and the chamber when shut up for forty-eight hours attained a temperature 4° below zero. The ice that formed on the pipes was very thin, and made very little difference in the conduction of the heat. The Author had also mentioned that the ether, ammonia, and other machines, worked in breweries under greater advantages than the air machines on board ship. But the reverse of this was the case. Where the machines were used to cool the fermenting rooms, the temperature was often reduced below freezing point. The rooms were not, as on board ship, kept closed and insulated with double walls and charcoal between; but doors and windows were open, and a current of air going through. In such rooms with brine pipes there was no difficulty in keeping the temperature below freezing point. The Author had said that the quantity of ice his machine would make was 5 lbs. per lb. of coal, and that the ether and ammonia machines would produce about the same. With Reece's ammonia machines the amount of ice made with 1 lb. of coal was 56 lbs. With the Reece machine the number of heat-units per lb. of coal was said to amount to 6,000, but with the improved Reece machine over 10,000 had been obtained. He thought, therefore, that the Author had hardly treated these machines fairly. He did not wish to detract from the merits of the Author's machines on board ship, where they had done very well; but the merits of other machines ought to be stated.

Mr. Coleman. Mr. COLEMAN, in reply, said with regard to the theoretical part of the subject, and the formula to which reference had been made, Dr. Siemens had acknowledged that it was an admitted formula of the scientific men of the day—one enunciated by Clausius and Sir William Thomson. He had given an illustration of the formula, and Sir Frederick Bramwell had asked him to look into it again. He had communicated with Sir William Thomson on the subject, who had stated that the illustration was correct. Mr. Cowper had stated that water injection was not correct in cold-air machines. He agreed with him that if there was no water in air, it was a foolish thing to put it in, but practically water was always present in air. He had shown in the Paper that repeated attempts had been made to make cold-air machines, on the theory that dry air was to be dealt with. It had been suggested that the air should be dried by chemicals, but he should be sorry to adopt that method on board ship, or indeed on land, for he believed it would be found very difficult. Mr. Haslam had opened the question whether surface cooling of the compressed air or water injection was the best. Mr. Coleman was perfectly indifferent on

that point. He used water injection, but he was quite willing to Mr. Cole use surface-tubes, and in fact in some kinds of refrigerating machinery had used them, and should still use them. The main point was to get the compressed air cooled down to the temperature of the water to be dealt with. Mr. Lightfoot stated that it required much more water to cool the air by direct injection than by tubes surrounded by cold water. He could not agree with that statement. No doubt Mr. Lightfoot would say that, in the case of cooling by surface condensation, the air could be passed in one direction through a tube, and water could be passed in an opposite direction, so that the compressed air went hot one way, and the water went cold the other way. The same could be done with injection. A small quantity of water could be injected in a pump and compressed air made to come from the pump; it could be passed up a tower and made to meet the water, facing it in an opposite direction; in fact a cooling effect could be procured with less water in the case of injection than with tubes surrounded with water. He had admitted that it was correct not to put water into air, if it was not already wet; but he had shown that air practically was never dry when it had to be dealt with. He had pointed out that moisture was deposited from air in the direct ratio of the compression. If anybody with a cold-air machine liked to use a pressure sufficiently high, the air would be dry without the use of the interchanger which Dr. Siemens had proposed, or without the use of the drying pipes which he himself had introduced into practice. In the Table, p. 156, would be found the ratio in which water was deposited for every 10° of cooling of compressed air. It was therefore the easiest possible thing to calculate how much compression of saturated air was equivalent to a cooling surface action by the drying pipes. He used the drying pipes because they enabled him to work his machines at a much lower pressure than he should have to use to produce the same degree of dryness of the air if he had no drying pipes. With reference to Mr. Mackay's remarks, the statement he had made as to brine pipes becoming coated with ice, as if they were enamelled all over an inch or two in thickness, preventing the transfer of heat, had been derived from two sources. The first was a report which he had received from Australia about two years ago, as to the ammonia machines used in Sydney, and which stated that there was a thickness of several inches of ice over the pipes used in cooling the meat. Meat at 80° or 90° gave off large quantities of steam, and if it was put pretty close in a room that had been cooled, say 1 ton in a space of 120 cubic

Coleman. feet, the quantity of vapour was enormous; it condensed on the pipes and rapidly froze if the brine inside them was at a very low temperature. He could understand that when the temperature was above freezing point, as in breweries, and where there was only a temperature of 40° , or even in the Atlantic traffic, where a temperature of 30° or 35° was employed, there would not be a thick coat of ice; but, in point of fact, there had been a great number of ships running during the last few years, in which the ice upon the pipes had amounted to 1 inch or 2 inches in thickness. He was quite certain that to freeze meat in a still atmosphere, with vapour constantly rising from it, would be a matter of great difficulty. Those who had made the most experiments on the subject in Australia, like the late Captain Farquahar, had found great difficulty with ammonia machines, or machines in which brine was circulated through pipes. With reference to the remarks of Mr. Hesketh, he was sorry if he had not been strictly accurate in stating the precise circumstances as to the three machines supplied to the Peninsular and Oriental Company. Six machines had been ordered by the Company many months ago. Three had been supplied by the Bell-Coleman Company, and three by other firms, but of the latter only one of the machines had gone to India and back. As to the injection of water corroding the interior of such machines, he had found that in the case of the "Kaiser-i-Hind" mentioned by Mr. Hesketh, some of the valves of the water pump, not more than an inch in diameter, corroded; but if phosphor bronze was used, such action was prevented. As to the machine used across the Atlantic, it had been found that after running two hundred voyages the repairs had been so slight that none of the compressors required to be bored out, none of the pistons to be replaced, and nothing had to be done to the compressor, except to some springs which were made of steel. They had since been made of brass, and no further trouble had been experienced. Wear and tear, in fact, rather improved the power of the machines to retain the air without leakage than otherwise. Mr. David Thomson had asked how it was that he had reduced air to 70° below zero, when a temperature of 25° above zero was required, to which he replied that the prime cost and the space occupied by a machine to circulate air, which was cooled through a small range of temperature, was utterly out of the question on board ship. As to the capacity of the chambers being quoted rather than the surface area, Mr. Schönheyder was quite right. The more cubic the chamber was, the less was the surface area, and therefore the more effective the

machine in dealing with it. Mr. Lighfoot had stated that the ratio of the steam cylinder to the size of the machine, or the supposed working power, was very large. It should be distinctly remembered that, supposing the whole of the power exerted in compression was restored back, the expansion cylinder would be of the same size as the compressor, and no steam power whatever would be required except to subdue friction, so that the ratio of the steam cylinder to that of the compressor was no indication of the power of the machine. The indicated HP. of the expansion cylinder to a large extent depended upon the temperature of the compressed air, and the higher its temperature at the time it entered the expansion cylinder the greater the power that would be recovered, but it would not be recovered power in useful cooling work, it would be recovered power in doing work which the water had not accomplished. It was in order to prevent mistakes on that point that he had enunciated the formulæ in the last page or two of his Paper. He had referred to Mr. Lightfoot's Paper read at the Institution of Mechanical Engineers, and he did not find that the results in any way differed from those obtained with his own machines. Although there was a certain difference in the ratio of power recovered, and the Table looked at first sight different, still, on going into the calculation it was seen that there was no essential difference in the results obtained. He had already dealt with Mr. Kilbourn's question relating to the action of sea-water, and he had now to mention another practical point in connection with that matter, that if water were not injected into a compressor it would have to be oiled, and the oil tainted the air; and if the air was used for making ice, the ice produced would be slightly tainted with the oil. That might be avoided by using glycerine; but it was important that the air should come into contact with the water that had to be frozen.

Sir WILLIAM ARMSTRONG, President, said he was sure the members would all feel much obliged to Mr. Coleman for bringing the subject before them. It was one not easily grasped by persons who had not made a special study of it; and not having himself given it any special study, he did not feel in a position to speak with any authority upon it. It was much mixed up with difficult questions relating to the transformation of energy and the relation of temperature to work. One interesting feature of the Paper was its reference to the non-production of cold when expansion took place without the accompaniment of work. To the uninitiated the machine did appear to form an exception to the general rule that all mechanical energy was ultimately converted into heat, for it

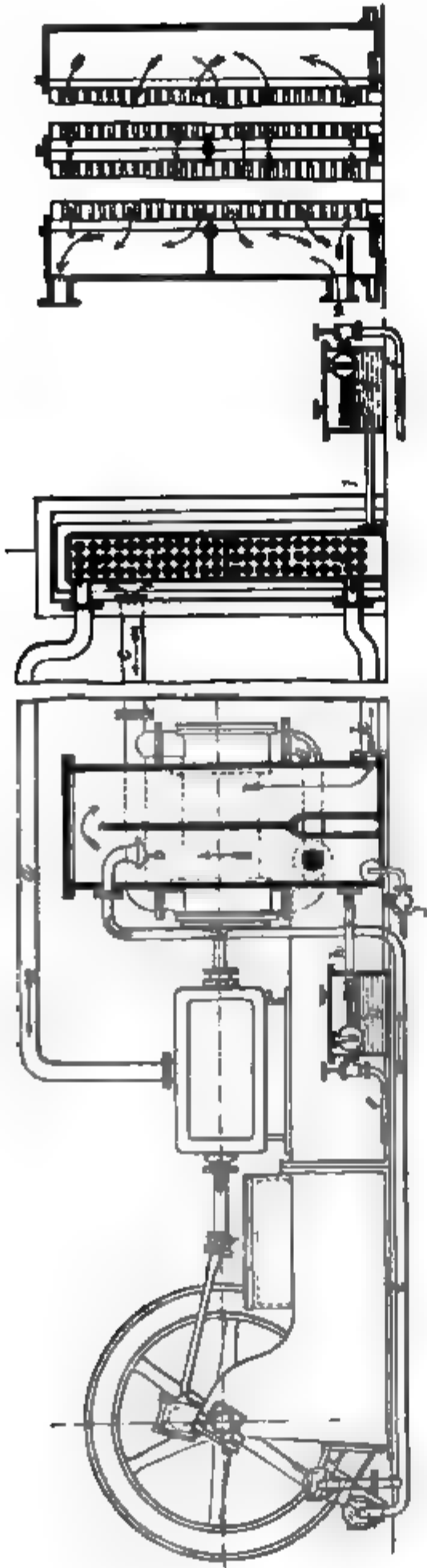
Sir William Armstrong. resulted in the production of an opposite condition. But looking a little more closely into the matter it would be perceived that the machine was really a heat-producing machine, and that cold was merely the result of the fact that the heat produced was abstracted from the air, which thereby became a medium of refrigeration. Like all inventions its progress had been gradual; each improvement being the result of experience and observation, and it was probable that it had not even yet attained full perfection and maturity. He hoped that the Paper and the discussion would tend to convey clearer ideas upon the subject, stimulate further progress, and lead to better results.

Correspondence.

Mr. Baldry. Mr. J. D. BALDRY remarked that as two of the Bell-Coleman machines had come under his personal superintendence, it might be useful to add some further details respecting that system. The particulars of the larger machine had been given in the Paper. The other, a much smaller machine, was employed for freezing fish, and bringing it in that condition from the Hudson's Bay Company's territory to this country. Fig. 5 showed portions of the machine, and illustrated the method adopted to cool the compressed air. As mentioned by the Author, the water was first injected into the compressor, upon leaving the compressor, the air passed into a tower, where it received a further spray. The law relating to the quantity of water which might be taken up as vapour by atmospheric air had been referred to, and it would be understood that the water diffused in the air in the tower was not absorbed, but fell to the bottom of the tower at once, and was discharged by means of automatic traps. The compressed air passed from the tower and traversed the lower series of pipes, returning by the upper series, and thence direct to the expansion cylinder. A simple method was adopted for arresting the water which was deposited as the air became cooler, and was caught at the intervening spaces and passed to the automatic trap previously indicated. The air to be cooled was drawn from the cooling chamber through the casing containing this nest of pipes, so that, soon after the machinery was put in motion, the process of cooling the compressed air was going on from the moment it left the compressing cylinder to its reaching the expansion cylinder, where it assisted to drive the machinery, and emerged

Mr. Baldi


FIG. 5.



- a. Pipe leading compressed air from drying pipes to expansion cylinder.
- b. Base.
- c. Air suction-pipe to compressors.
- d. Discharge from compressor to tower.
- e. Discharge pipe leading from water pump to tower for the injection of water.
- f. Water discharge from trap to ship's side.
- g. Water trap.
- h. Water drain-pipe from tower to trap.
- i. Do. do. ship's side.
- j. Compressed air from tower to drying pipes.
- k. Drain pipe, drying pipes to trap.

Mr. Baldry. from the exhaust port generally about 50° below zero. The deposit of snow in the delivering chamber was small, and the air was practically dry. The vehicle by which the heat was subtracted from the air was evidently the water injected into the compressor and the tower; its cooling power was direct and very effective. He had found that the quantity of water used per 1,000 cubic feet of compressed air was about 40 gallons. This reduced the temperature to within a few degrees of that of the water, and the air was further cooled 10° to 15° in passing through the pipes, reaching the expansion cylinder at a lower temperature than the outer air. Having made some investigations into this subject, he might add, with regard to refrigerating machines generally, that the chemical method of cooling air, whether by ether, ammonia, or sulphurous anhydride, had the advantage of economy over the purely mechanical means, but here, he thought, the advantage ended. Where the object was to cool or freeze meat, or for use on board ship, there were objections to the use of chemicals. Some of the other mechanical refrigerators had great merit, and their method of cooling the compressed air by means of water-jackets and surface-condensers, instead of by direct contact with water, was undoubtedly the best, if it were so effective. At present he had not seen any that had attained the object required more completely than by the arrangement described by the Author of the Paper. Improvements were daily being made in these machines, and there had been great progress during the last twelve months; perhaps in a year or two this method might be superseded by a better system, but it was only fair to say that the present machine performed its work satisfactorily and efficiently.

Mr. Galwey. Mr. J. W. de V. GALWEY observed that the expression, "a cubic foot of air, in contact with water, contains exactly the same amount of vapour, whatever might be the density of the air," was an incomplete statement, so far as it applied to mechanically-compressed air, inasmuch as the temperature of the air was not considered; it was well known that a rise of temperature increased the capacity of the air for moisture, other circumstances remaining the same. From the above incomplete statement the inaccurate conclusion had been drawn that compressed air of usual humidity was not made wetter by injection of water, provided the surplus of water was run off continuously by automatic traps. From this many might be led to suppose that the possibility of continuously removing the surplus moisture was an accomplished fact; but, so far from this being the case, at collieries and other similar places, where



compressed air was largely employed, the underground hauling Mr. Galw engines were much more encumbered by ice where wet compressing was used than where dry compressing was resorted to, and this, too, with ramifications of pipes and receivers, which acted as moisture depositors, and were provided with drain-cocks, which from their great extent would be inadmissible in connection with a cold-air machine. The Author had also added, "air being actually dried by compressing it in contact with water, removing the water and expanding," but without the slightest attempt at proving the assertion; and the fact above referred to went a long way towards proving the contrary. As to the contention that direct injection was the quickest and most effective method of cooling air to the temperature of the water, the Author had apparently overlooked that this water must afterwards be in some way condensed, and that he wasted far more power in producing snow, which was the method in which he must precipitate the surplus moisture, than he could economise by directly injecting the water, on account of water, in addition to its specific heat being greater than air, absorbing 142.4 negative units in turning to snow or ice, which units of cold were lost to the air delivered to the cooling chamber. The Author had evidently neglected two further facts, viz., that the compressed air could not be cooled to the temperature of the injection water prior to its injection, for in cooling the air the water must absorb heat, thus raising its own temperature, and by consequence its tendency to evaporate; and that the air, in its passage to the expansion cylinder, swept along at a velocity which did not give it time to deposit much moisture, but rather the reverse. With respect to the Author's conclusion, "that every lb. of vapour unnecessarily condensed liberates as much heat as will raise about four thousand times its weight of air 1° Fahrenheit," there was a direct contradiction to his own assertion as to the economy of injection. He would ask the meaning of "unnecessarily condensed"? The Author could not mean that he would allow all the vapour to pass through the machine, since he prevented this, and if not, why did he not state the amount he considered necessary, especially as the concluding sentence of the paragraph seemed to indicate that he had made the discovery? If the Author had discovered the degree of moisture proper under all circumstances, and for various kinds of food, as well as animals, he could only say the task must have been a Herculean one. As to the mode of liquefying the vapour suggested by the Author, being by the wasteful process of using cold already produced by the machine for that purpose, he would simply say that whereas, with im-

Mr. Galwey. perfect appliances, such a method of liquefying the vapour in the compressed air might be necessary, yet it must be obviously a wasteful way of doing so, and that the liquefaction, or rather removal, of the vapour was accomplished in the "John Sturgeon" cold-air machine in a far simpler and more efficient manner, without wasting any of the cold produced by the machine, and in addition purifying it.

Dr. Pole. Dr. W. POLE wished to remark that, when a gas under pressure issued spontaneously out of a vessel, work was undoubtedly done, not only in moving away the surrounding medium, but to a much larger extent in giving motion and velocity to the gas itself. The amount of work thus applied was much greater than was usually supposed. To take an example; suppose a large vessel to be filled with air compressed to 10 atmospheres, and standing at the ordinary temperature. If a hole was made in the side of the vessel, the gas would rush out with a velocity¹ of nearly 800 feet per second. And supposing the hole had an area of only 1 square inch, the quantity of air escaping would be about $\frac{1}{4}$ lb. per second, and to give this the requisite velocity would require an amount of work equal to about 2,350 foot-lbs. every second of time, or 4 HP. This could only be furnished by the compressed air, and it was matter of common experience that in all such cases heat was lost in the operation. It was a well known example that the hand might be held, without scalding, in the steam issuing from a safety valve, provided the pressure in the boiler was sufficiently high to produce a large sudden expansion.

Sir William Thomson. Sir WILLIAM THOMSON remarked, that setting aside as chimerical, in respect to practical purposes, any drying of the entering air, whether by chemicals or by compression, the result to be dealt with was essentially that air, in all ordinary atmospheric conditions, contained so much moisture that its dew point was far above the temperature to which it had to be cooled. In fact, unless the natural atmospheric temperature was below the freezing point, or so little above it that there would be no need for the refrigerator, the dew point was scarcely ever as low as freezing. Hence, as the air must be reduced to the condition of fog or mist in the action of the machine, it could not be made more wet by the injection than it would be without it. Accordingly there was no advantage in respect to dryness, in the process of cooling by external application of water, over that by injection; and it seemed clearly proved by the Author that there were large counterbalancing advantages (many of which, indeed, were obvious

¹ According to formulæ in Rankine's "Rules and Tables," p. 302.

to any one acquainted with mechanics) in favour of the process of cooling by injection. Sir William Thomson felt much interested in the Author's machine, and admired it greatly as a practical realisation of the method for producing heat or cold thermodynamically, which he had pointed out twenty-nine years ago, in a communication to the Glasgow Philosophical Society (December, 1852), "On the Economy of the Heating or Cooling of Buildings by means of Currents of Air."¹

Professor C. PIAZZI SMYTH remarked that the rapidity with which the subject under discussion had emerged, within the last few years only, from the experimental stage into something like completed practical perfection, and the enormous scale on which refrigeration was now worked, in one at least of the special applications, was as meritorious to the engineering profession of the day as beneficial to the progress of the country. He had occupied himself many years ago with this very subject of cooling air by the expenditure of mechanical power; but for a long time he could get no one to listen to his argument, until he became acquainted with—first, the late James Stirling, of Dundee, of air-engine fame, and afterwards with the late Professor Macquorn Rankine. The latter quickly perceived the importance of the matter, and, after much consideration, decided on the simple mechanical method as being the best, and took much trouble in explaining to him the proper thermodynamical method for dealing with a compressible gas. A sort of experimental machine, or tool merely, on that plan, was eventually made for a Crimean hospital, but only of one-man power, and chiefly of economical carpentry materials. Yet the one part of the problem, which had been foreseen by theory, was very fairly solved by its working. He need say no more of those early labours, because the Author had given them even more than their full meed of praise; but he would wish to declare explicitly, that the particular application for which the Author had latterly used the principle was one that never crossed Professor Smyth's mind. To himself it was almost "like life from the dead," to find, after twenty-seven years, that the leading principle of Professor Rankine's and his own long-lost-sight-of little machine was now largely governing the movements of a fleet of steamships to all parts of the world, and bringing to this country a new class of freight to assist in the growth of the nation. But that leading principle alone would not have been enough, and the Author had further to devise an effective method for dealing with the invisible vapour of water, which

¹ Proc. of the Phil. Soc. of Glasgow, vol. iii., p. 269.

Prof. Smyth. was always present more or less through all the habitable strata of the earth's atmosphere. In this the Author had attained complete mastery, for at one part of his operations he actually injected water into the compressed air without increasing its humidity; and at another part extracted all baneful excess of the original moisture by a clever application of the cold produced by the machine itself. There was only one further point to which he would direct attention. The purpose for which Professor Rankine and he proposed to employ air-cooling machinery was for cooling the air of hospitals and dwellings in tropical lands. That purpose stood exactly where it did in 1855, for it was not in use yet, nor had the beneficent end proposed been carried out by any other method. No plan that had not the power of greatly lowering the temperature of the air, and decreasing the invisible watery vapour in it to the same moderate amount in which it existed in the British Isles, could ever impart the same health and strength to our failing countrymen in India. But the Author's air-cooling machines had all that capability; and he had even sketched out a scientific variety of machines for a large hospital in India. This machine, though its great size and necessary first cost were indicated by the 150 HP. required to work it, could supply daily cooled air to each one thousand inmates at a very trifling expense per head.

Dr. Zeuner. Dr. GUSTAV ZEUNER objected that the Author had confined his observations to cold-air machines. Having had much experience with "cold-steam engines" Dr. Zeuner preferred them on theoretical as well as practical grounds.¹ Although it was perfectly correct that the temperature could be lowered much more by cold-air refrigerators than by cold-vapour refrigerators (when ether or ammonia was used), the mechanical theory of heat showed that mechanical action became more and more imperfect at the same ratio at which the temperature was lowered, and as the temperature requisite for the cooling of meat or the production of ice was not much under 32° Fahrenheit, Dr. Zeuner was of opinion that a vapour system was preferable, as it required much less engine-room. It was also his belief that the action of cold vapours was much more energetic than that of cold air, and that Pictet would never have arrived at the results he attained had he conducted his experiments with cold air, instead of a combination of sulphuric and carbonic acid. In conclusion he expressed his conviction the vapour refrigerators would supersede cold-air machines in future, provided chlor-methyl or ammoniac were used instead of ether.

¹ *Vide post*, p. 400.

Mr. COLEMAN in further reply upon the discussion and on the Mr. Coleman correspondence, stated, in regard to the illustrations of the formula given on p. 167, for calculating the efficiency of cold-air machines, it might be mentioned that the average minimum temperature of the expansion cylinder exhausts represented by cards 15, 18, and 21, was 400° absolute (Plate 3). It would also be noticed from cards 14, 17, 20, and 23, which were a fair representation of about one thousand sets of cards taken by the Author during the preceding two years, that the compression was approximately isothermal, thus disposing of the objections raised by Mr. Haslam, Mr. Galwey, and others, who assumed that with water injection the compressed air attained temperatures of 300° , or thereabouts. The air leaving the compressors with water-injection had seldom in the Author's experience exceeded 20° above the temperature of the injection water. It was for dealing with this last 20° of heat of the compressed air that the Author had adopted the method of making the compressed air, after leaving the compressors, meet with a rain of cold water in what he called the water tower. Too much importance could not be attached to bringing the compressed air, not only nearly, but almost absolutely, to the temperature of the cooling water. Good cold-air machines were supposed to cool through a range of 150° below what could be effected by the agency of the natural water at command for cooling purposes, but if by ineffective cooling of the compressed air before expansion the air was 15° warmer than it should be at the moment of entering the expansion cylinder, then the effective duty of the machines would be reduced 10 per cent.

In reference to the employment of an interchanger, the Author would observe that if employed in the waste current of air the terminal temperature would be reduced correspondingly, and the effective range of cooling would still be the difference between that at entering and leaving the expansion cylinder; but if the interchange was in a derived current of cold air then the degrees of heat lost by the compressed air must be deducted from the effective mode of cooling. He desired to say in connection with the subject of interchangers, that Mr. Haslam's remarks about his collector and separator, did not at all do away with the fact that such apparatus was merely a variation of the Author's method of cooling the compressed air by some of the cold produced by the machine itself, and his figures about space occupied by machines did not include 2 feet working space all round the machine allowed in the Author's figures. Mr. Mackay had misunderstood his remarks as to India. The Author did not propose cooling air

Dr. Coleman. to 30° but through a range of 30° , and not exactly by the machine taken as the basis of calculation, but by machinery specially constructed for working large volumes of air at low pressures.

As stated in the discussion, the Author believed it was immaterial in practice whether the compressed air was cooled by direct injection of water or by surface cooling in tubes, provided it was reduced to the temperature of the water available for cooling, direct injection being decidedly the simplest way of effecting the object. The cooling by surface tubes was more expensive in first cost of machinery and involved the employment of grease, or other lubricant, in the air pumps, which contaminated the air and which was liable to get cloggy by oxidation, or from dust being sucked into the pumps, and to interfere with the working of the valve. This was a practical difficulty of a serious character in such machines as were employed in cooling down rooms in dusty climates, or on vessels when grain cargoes were being taken on board; which filled the atmosphere with fine dust. Up to the date of the Author writing this Paper 90 per cent. of the work by British-made machines had been done by such as had been constructed to work by water-injection, and the dryness of the air produced by such machines had been so great that calico or paper kept in the rooms being refrigerated took fire on application of a light. A good many machines on the other system had been made, but very little worked and that intermittently. Further the Orient Steam Navigation Company had now brought from Australia two cargoes of meat of about 150 tons weight each, refrigerated by machines in which the compressed air was cooled by water-surrounded tubes, and two exactly similar cargoes, in which the compressed air was cooled by direct injection of water. The logs of such voyages had been compared and showed that so far from the surface-tubes arrangement giving better results than the water-injection arrangement, the air produced by the latter system was quite as free from snow, and was produced as economically as that by the former system, whilst the machinery was simpler. The system was at present being adopted in fitting up machinery on the two Orient line steamships "Lusitania" and "Chimborazo" under the superintendence of the Author, for cooling 60,000 cubic feet of air per hour.

The Author would also like to state that on perusing Dr. Siemens' report he did not find it by any means so nearly approaching an anticipation of his plans as Dr. Siemens' remark had led him to expect; but whatever opinion might be formed

on that point was immaterial, seeing that Dr. Siemens had since Mr. Coleman informed him that the proposals in question were never practically carried out; and the Author was unaware of them until long after his machinery had been practically at work.

Mr. Coleman could trace no analogy between Mr. Cowper's illustration of opening a cock of a boiler containing steam superimposed over a layer of water to the operations of cold-air machines of the present day, as no water was in contact with the air undergoing expansion in such machines, and which were the conditions of the trials twenty years ago by Mr. Wollaston Blake, when brine was injected into the expansion cylinder.

21 February, 1882.

Sir W. G. ARMSTRONG, C.B., F.R.S., President,
in the Chair.

The discussion upon the Paper "Air Refrigerating Machinery and its Applications," by Mr. J. J. Coleman, occupied the whole evening.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 1685.*)

“The Rokugo River Bridge and Foundations on the Tokio-Yokohama Railway, Japan.”

By RICHARD VICARS BOYLE, C.S.I., M. Inst. C.E.

It is not intended in this Paper to invite particular attention to the superstructure of the bridge, which is of an ordinary character; the chief object is to give an account of the foundations, which it is thought present features that may be of interest to the members.

The works necessary were of some magnitude and offered unusual difficulties both in design and in execution; and it is believed that the data furnished by experience in carrying them out may probably be useful for engineering practice generally. The bridge herein described is the second constructed to carry the railway, connecting Yokohama, the chief port of Japan, with Tokio or Yedo, the capital, 18 miles distant, over the river Rokugo which is crossed about halfway between the two places. This river, navigable for small coasting craft to a short distance above the railway bridge, is subject to considerable floods during the rainy season, owing to the extent of country which it drains and the elevated and precipitous character of the districts bordering the watershed. Accordingly it is found that the ordinary flow is confined to a channel occupying only from one-fifth to one-tenth of the width comprised between the flood-banks, or about 300 feet out of 2,000 feet at the point of crossing.

The first bridge, on the original line of the railway, was constructed with native timber, the use of which largely in all bridge and culvert works was decided upon by the former Engineer-in-Chief, the late Mr. Morel, Assoc. Inst. C.E., in compliance it is believed with the request of the Government, and with the view of offering facilities for the employment and instruction of native workmen, amongst whom the carpenters form a numerous and intelligent class. The fallacy involved in this decision (no matter how praiseworthy the motives which led to it) must have been evident to the Engineer-in-Chief, and is probably now equally clear to the Government, who, within two years of the opening of the line for

traffic, gave orders, under the advice of the Engineer-in-Chief, the Author of this Paper, for the renewal of all the bridges and culverts with iron superstructures and permanent foundations and piers, in view of the advanced state of decay into which the original structures had fallen. The timber used throughout these works was of three descriptions, called Hinoki, Matou, and Keyaki, of which the first two are not unlike American white pine, being soft and easily worked though less durable, while the last in strength and appearance resembles teak. The rapid decay of these materials is, however, to be ascribed in great measure to the circumstances under which the timber was supplied for use. The ordinary trade in timber, a very extensive one in Japan, is founded upon the native system of building, to which such structures as are required in railway bridge-work are entirely foreign; and instead of well-seasoned timber being supplied, it was a frequent occurrence, in order to obviate delay, for the timber to be felled without regard to the time of year, brought on to the works in a green state, and immediately used without any preparation or seasoning.

The result was that in June 1875, only three years after the completion of the work and less than five years from its commencement, the original bridges were reported by the District Engineer, to be in such a state that the life of the largest, that over the Rokugo river, could not exceed one year more. This report was fully verified, as it was only by the greatest care and attention, and constant and costly repairs, that the bridge was made to serve the requirements of the traffic until replaced by the new one, which was opened officially by Mr. Ito Hirobumi, Minister of Public Works, in November 1877. As the construction of the railway was only commenced in 1870, it will be seen that the life of the original timber structure was barely seven years, a surprising result when compared with the more satisfactory experience of timber-work in other countries, but mainly accounted for by the facts already mentioned. At the present day good sound and well-seasoned timber of large size is much less difficult to procure; so that the unfortunate experience herein detailed may be regarded in some degree as attendant upon the changes, social, commercial, and political, that Japan was then undergoing, and in which the introduction of railways was a conspicuous incident.

In selecting a site for the new bridge, which for obvious reasons of convenience was so laid out as not to interfere with the original one, the faulty alignment of the railway at this point was corrected. The timber bridge consisted of seven openings with truss girders

of $56\frac{1}{2}$ -feet span = $395\frac{1}{2}$ feet, placed at a considerable angle to the stream, and continued by one hundred and twelve openings of 15 feet each = 1,680 feet, great part of which was on a curve of $\frac{1}{2}$ -mile radius, giving a total length of $2,075\frac{1}{2}$ feet. By diverging from the original line south of the river with a short curve of $\frac{1}{2}$ -mile radius, a straight lead across the bridge was obtained, the junction with the original line north of the river being effected by another curve of $\frac{3}{4}$ -mile radius; the new alignment was less oblique to the main channel of the river than the old one, and the deviation was 2 chains shorter than the original line. It was further considered desirable that greater headway should be given than had been allowed in the old bridge for exceptional floods, and a slight increase of the gradients on both sides of the river was accordingly required, the new bridge being approached by an incline of 1 in 100 for 12 chains on the south, and an incline of 1 in 152 for 16 chains on the north side of the river; the rail level thus attained was 20 feet above ordinary high-water mark and 6 feet above the highest known flood-level.

A careful estimation of the volume of water discharged during maximum floods, and consideration of the general regimen of the river, resulted in its being found possible to reduce the length of the bridge; and a portion of the flood area within the north bank was occupied by an embankment, leaving an intervening distance of 1,650 feet, which was bridged as follows:—

From the north abutment	23 spans of 40 feet clear	=	920 feet.
"	"	"	1 span " 38 " = 38 "
"	"	"	6 spans " 92 " = 552 "
<hr/>			
Total 1,510 " waterway.			
"	"	"	23 piers 4 feet thick = 92 feet.
"	"	"	6 " 8 " diameter = 48 "
<hr/>			
Total 1,650 " between abutments.			

The piers of the smaller openings were all placed square with the centre line, the remainder of the piers on a skew corresponding with the angle of the stream, viz. 75° . The twenty-fourth opening from the north side is thus wider upstream than down, and the clear span given is that on the centre line of the bridge. The twenty-four small openings are spanned by plate girders 3 feet deep, placed one under each rail of the double line, and braced together in the usual way; the two outer girders also carry cantilevers supporting footways and handrails; all these girders are discontinuous, and

rest upon cast-iron bed-plates. The north abutment and twenty-three piers are of substantial masonry and brickwork founded upon concrete resting upon compact strata of sand and gravel, and protected from scour by sheet piling, as it was decided to make these foundations as shallow as possible to avoid breaking through the gravel, which has a thickness of from 9 to 11 feet and is underlain by more than 40 feet of soft mud and silt.

The larger openings are spanned by Warren girders, 100 feet long each, 11 feet 4½ inches in extreme depth, with a clear width between the two girders composing each span of 22 feet, the double line of rails being supported by cross-beams 2 feet deep in the centre and 1 foot at the ends, resting upon the bottom booms of the main girders, and spaced from 5 to 6 feet apart. The main girders rest upon cast-iron bed-plates, on which they are fixed at one end, while free to slide at the other to provide for expansion.

Piers 24, 25, and 26 are each composed of two brick cylinders or wells 12 feet in external diameter, resting upon a stratum of volcanic ash immediately below the mud and silt at a depth of about 79 feet from the rail level, and are filled with concrete. Just under ground-level the diameter is reduced to 8 feet, and solid masonry columns of this dimension are carried up to the underside of the girders and finished off with a bold capital. The space between the two columns in pier 24 is arched over beneath the ground, and an intermediate wall built to carry the ends of the girders of the adjoining small span.

Piers 27, 28, and 29 each consist of two cast-iron cylinders 8 feet in external diameter, resting upon a hard stratum of gravel a little lower than the volcanic ash above-mentioned, at about 88 feet from the rail level, and filled with concrete. The upper part of these cylinders corresponds in appearance with the masonry columns of piers 24 to 26, and the pair forming each pier are braced together between low-water mark and the cap with horizontal and diagonal bracing composed of channel irons and stiffening bars, attached to the columns by rings around the latter.

The south abutment is founded upon four brick wells similar to those of the piers, the spaces between them being arched over below ground, and this foundation is surmounted by brick front and wing walls with stone groynes.

The works are from the designs of Dr. William Pole, M. Inst. C.E., Consulting Engineer in England, and of Mr. R. Vicars Boyle, C.S.I., Engineer-in-Chief in Japan, and the ironwork was manufactured under the inspection of Dr. Pole, by the Hamilton Windsor Ironworks Company, Limited.

The ironwork having arrived from England, and other materials being in readiness, it was decided in the month of June 1876 to proceed with the works. However, as the highest floods usually take place in the early part of September, it was considered inexpedient to commence the work of sinking the cylinders for piers 27, 28, and 29, forming the piers in the river bed, until after that month. This objection did not apply to the abutment cylinders on the Yokohama (south) side, or to the cylinders of piers 24, 25, and 26, because the level of the ground at the abutment is above ordinary flood-water mark, while on the Tokio (north) side of the river bed, where piers 24, 25, and 26 are placed, the ground is dry at ordinary tides, and it was anticipated that satisfactory progress could be made before the September floods set in. These portions of the work were therefore at once taken in hand.

The brick cylinders are 12 feet in external diameter and 2 feet thick. The bricks are laid in hydraulic mortar, composed of 2 parts of selenitic cement, 1 part of Portland cement, and 6 parts of fine clean washed sand. The whole is well tied together by rings of wrought iron built in the brickwork, through which tie-bolts $1\frac{1}{2}$ inch in diameter run vertically the entire height of the cylinder. These bolts are securely fastened to the curb-shoe and cottered tight on to the rings, which are placed at an interval of 10 feet apart. The curb-shoe is formed of plate- and angle-iron filled in with wood to a depth of 2 feet, the whole well bolted together and making a solid platform for the brickwork to rest upon. The outer side, constituting the cutting edge of the shoe, is in a line with the sides of the cylinder, while the inner side is formed with a slope or angle of 60° . To facilitate sinking, and to give some clearance to the body or outer surface of the cylinder, the shoe is made 12 feet 6 inches in external diameter, and the first 4 feet in height of brickwork built upon it is made to taper backwards to 12 feet. The experience gained on this work, as well as on similar works executed in Japan, makes it doubtful if any advantage is derived from constructing the shoe and lower portion of the brick cylinder of larger diameter than the remainder of the latter; the earth settled round the body of the cylinder as it sank, causing a side friction as great perhaps as would have been the case had the shoe length been of similar diameter to the whole cylinder.

The cylinders are sunk through an average depth of 56.80 feet (the maximum depth being 60.67 feet from ground-level) by the following operations: The site having been levelled and the shoe placed in position, the building of the brickwork upon it was commenced, the workmen being guided by suitable templates.

A height of 10 to 15 feet of brickwork was first completed, the outer surface being coated with selenitic cement in the proportion of 1 part of cement to 4 parts of sand, with the object of presenting a smooth surface to reduce side friction. Fifteen to twenty days were allowed for the cement to become thoroughly set before sinking commenced. The two cylinders forming each pier were sunk alternately in lengths; this was found to be the most expeditious way of executing the work, and by avoiding any great difference of level at any time between the two cylinders, the tendency which was observed for the last sunk of a pair to diverge from the perpendicular was avoided.

For excavating inside the cylinders various appliances were employed. Bull's hand dredger was at first used, and did satisfactory work in the stratum of fine sand near the surface, but in coarse gravel and soft mud the efficiency of the hand dredger became much reduced. Kennard's improved sand pump was accordingly tried; this did good service in the coarse gravel, but was not found suitable for dealing with the mud. When this latter was reached, at an average depth of 14.73 feet from the position of the shoe before sinking was commenced, the rapid inflow of water, which had not been met with to any material extent up to this stage of the operations, caused considerable difficulty. It was feared that throughout the mud stratum the same difficulty might continue to recur at intervals; so, in order to obtain definite information on this point beforehand, a small trial well was sunk, and the result was to establish the fact that the flow of water occurred at the junction between the coarse gravel and the mud, below which point for several feet the mud was comparatively dry. The excavation was continued to a depth of several feet below the shoe by a bag excavator (Plate 4, Figs. 1, 2, and 3), and the building of an additional height of cylinder was proceeded with in the expectation that the increased weight thus applied would force the cylinder past the water-bearing stratum, thus stopping the inflow and enabling the excavation to be continued. It was found, however, that even an extra height of 20 feet of brickwork, which raised the dead weight of the cylinder to more than 100 tons, produced not the slightest appearance of sinking, notwithstanding that the outside had been carefully cemented. It was then decided that one cylinder should be weighted until sinking took place. The result led to the conclusion that side friction in cylinders used for foundations is of much more importance than has generally been allowed or taken into account; and to enable more decided conclusions to be formed from actual data, careful records were

kept throughout the subsequent progress of the sinking operations. On this first occasion the actual weight of the cylinder, together with the load applied, amounted to nearly $7\frac{3}{4}$ cwt. per square foot of side surface before the cylinder moved, when it sunk through a depth of over $2\frac{1}{2}$ feet. The inflow of water ceased, and, the cylinder being cleared out, the excavation was continued by hand labour, additional weight being applied to cause sinking from time to time.

The bag excavator is a simple tool, which was found most useful for excavating under water, and had been previously used on similar works on the southern main line in Japan. It consists of two bags, each fastened to a frame of iron, the lower part of which formed a cutting edge; these frames were fixed on opposite sides of a vertical bar, by which they were made to turn round and dredge out a circular hole. The original details were much improved upon at the Rokugo bridge, and for use in deep wells the two frames were bolted to a square intermediate socket, fitting loosely on a vertical rod which remained suspended in the cylinder while the frame and bags were lifted and emptied at the surface. Any required pressure upon the bottom, to make the cutting edges effective, was obtained by loading the frame with weights slipped into a cross-bar attached to it. This bag excavator was superior in power and handiness to Stoney's helical excavator, which was tried in several of the cylinders; and when the presence of water in the bottom prevented hand labour being employed in excavation, the bulk of the work was executed by this means. In general eight men were able to turn the bag excavator by bearing upon tillers keyed to the vertical rod, and under favourable circumstances from four to six lifts an hour could be made, each operation bringing to the surface 5 or 6 cubic feet of material with the small-sized excavator first tried, and 12 to 16 cubic feet with the larger one subsequently made for use in the cast-iron cylinders.

On the cylinders of 24 pier reaching a depth of about 58 feet from the level at which the sinking was commenced, a stratum of volcanic ash, overlaid by 2 or 3 feet of yellow clay, was met with, the inflow of water from which was so rapid that it was with great difficulty the workmen in the cylinder escaped before the cylinders were filled, and overflowed at a level of 5 feet above the water in the river. As this discharge evidently was derived from some elevated source, it was allowed to take its course for several days, without however diminishing in volume; but by sinking the other cylinders into the same stratum, the flow was distributed amongst the whole, and after a time became inconsiderable. It was thought

that this stratum, below which was a bed of hard blue clay overlying the gravel upon which it had been at first intended to found the cylinders, would afford a sufficiently good base without further sinking, and the brick cylinders were therefore cleaned out on attaining this depth. The final weight was then applied, equal with the brickwork of the cylinders to $506\frac{1}{2}$ tons on each, and allowed to remain for eight days, during which a sinking of only a few inches resulted. The weights being removed the cylinders were cleared of water without difficulty, and filled with concrete. The average rate of sinking was a little more than 2 feet per working day of ten hours, during the actual process of excavating, in each cylinder.

No material interruption of the work on the brick cylinders was caused by floods, and the season for these having passed by, operations were commenced without delay on the cast-iron cylinders of piers 27, 28, and 29. As the sinking had to be commenced in a depth of water varying from 4 to 9 feet at low water, different arrangements were made to those adopted for the brick cylinders. An ordinary staging (Plate 4, Figs. 4, 5, and 6) was constructed over the river, supported on timber piles driven 14 feet apart in the width of the river and 17 feet apart up and down stream. This staging extended from the north side of the main channel to a short distance beyond the position of pier 29, leaving an unobstructed passage for the boat traffic alongside the south bank. All materials for the cylinders and superstructure were landed on the north side of the channel, except two of the main Warren girders for the last span, which were put together on the southern side. Around the site of each of the cylinders the staging piles were driven close together in groups of four piles to each cylinder, and cross and guide timbers were bolted to them, the lowest of which were set some distance below low-water mark; these guide pieces were adjusted to keep the cylinders in true position during the process of sinking. Planking was placed to form a platform around the top of each cylinder, and a centre gangway, along which a tramway was laid, traversed the entire length of the staging. The outer beams of the staging were 39 feet apart, and provided with rails upon which a 30-ton Goliath traveller was mounted so as to command the whole of the staging and cylinders. The central tramway was put in communication with another leading to the landing-place, by means of a turntable between piers 26 and 27. At a convenient spot the segments of each ring of the cylinders were bolted together and placed on a truck, which was then brought along the central tramway to the cylinder for which the ring was required, and on to which it was lifted by the travelling crane. As many rings were loaded on each

cylinder at one time as could be conveniently done before moving the travelling crane to another spot.

The bottom ring, forming the shoe of the cylinders, was 4 feet deep, with a suitable cutting edge, being made extra strong and stiffened internally with ribs; the metal was 2 inches thick, and the whole weighed 4 tons. The succeeding rings were all 6 feet deep, of metal $1\frac{3}{8}$ inch thick, and weighed 4 tons each. Each ring was composed of four segments, and the vertical and horizontal joints were provided with flanges planed to a true surface; the segments of the 6-foot rings were of the same dimensions and interchangeable, and the bolts were alike throughout. All the joints were caulked with iron-cement so as to be watertight. The first two or three lengths of each cylinder were united before being lowered into position, so that the subsequent operations of joining the rings could be carried on above water.

The excavation was conducted nearly in the same manner as in the brick cylinders. After the first strata of fine sand and of gravel had been passed through, the mud seemed of a less compact character than had been the case at the other piers. A trial was again made with the various excavators previously used, but the most satisfactory results were afforded by the bag excavator made on the works, which seldom failed to bring up a full load of spoil, and the excavation and sinking of the cylinders proceeded regularly until the hard gravel was reached. The final loading amounted with the weight of the cylinder itself to a little more than 253 tons, and this was allowed to remain for eight days, during which time an average sinking of 4 feet took place.

The cylinders were next cleared out by a diver, and all earthy matters that had lodged on the sides and flanges removed. They were then filled with concrete to a depth of 10 feet, lowered in boxes, and composed of 1 part of selenitic cement, 1 part of Portland cement, and 10 parts of gravel. Fourteen days were allowed for this to set, after which the water was drawn out, and the filling continued up to within 15 feet of the top by the boxes, and the remainder thrown in. The average rate of sinking during the actual process of excavating was over $2\frac{1}{2}$ feet per working day of ten hours in each cylinder.

The piers of the smaller openings, and the abutments above the foundations, present no special features calling for a detailed description.

The whole of the ironwork for the superstructure was sent from England in pieces, which were put together and the joints riveted-up on the works.

The ten Warren girders on the north side of the main channel were first erected on a convenient site near the bridge, and then brought by ordinary appliances into the line of the piers, the upper masonry of pier 25 having been left unfinished to the last in order that this might be done with facility. Each girder was lifted by the two travelling cranes, which, with their load, were hauled forward to the required position, and the girder was lowered on to the bedplates. On the cast-iron cylinders of piers 27, 28, and 29 the bedplates were held in position by adjustable bed-frames built into the concrete, by which arrangement any slight deviation of the cylinders from the vertical position was corrected.

The two Warren girders, which had been put together on the south side of the river, and intended for the span between pier 29 and the south abutment, were launched on sliding ways until they projected sufficiently over the river for the outer ends to be supported by boats, after which they were again moved forward until within reach of the travelling crane on the staging, by which they were placed in position on the bedplates.

The pieces composing the plate girders for the smaller spans were put together alongside the respective openings they belonged to, and after being riveted-up were lifted on to the piers by the travelling cranes, and the bracing and cantilevers fitted and riveted on.

The total weight of ironwork in the bridge is as follows :—

	Tons.
Cast iron in six cylinders	360
" " bedplates, &c.	15
Wrought iron in cylinder bolts, bracing, curbs, &c.	35
" " 24 spans of 40 feet each	490
" " 6 " 100 "	420
Total	1,320

The time occupied in erecting the entire work was seventeen months. The works were placed in the special charge of the late Mr. Theodore Shann, Assistant-engineer, as Resident, under the superintendence of Mr. T. R. Shervinton, M. Inst. C.E., and the late Mr. John England, M. Inst. C.E., successively.

The following Table, representing the effect of side frictional resistance, has been compiled from the notes made during the process of sinking the cylinders. For simplicity the various minor weights applied to assist the descent of the cylinders have not been quoted in detail, though taken into account in the totals given as necessary to move the cylinders at the respective depths noted. The difference of diameter between the brick and the

BRICK CYLINDERS.

	A.				B.				C.			
	Pier 24. Up- stream Cylinder.	Pier 25. Down- stream Cylinder.	Pier 26. Up- stream Cylinder.	South Abutment. Front Down- stream back Cylinder.	Average Results.	Pier 26. Up- stream Cylinder.	South Abutment. Front Down- stream back Cylinder.	Average Results.	Pier 24. Up- stream Cylinder.	Pier 25. Down- stream Cylinder.	Pier 26. Up- stream Cylinder.	South Abutment. Front Down- stream back Cylinder.
Depth from surface of ground when weights were applied. . in feet	13.08	11.50	13.75	17.66	17.66	14.73	22.50	18.75	16.33	45.75	81.02	56.50
Sinking weights, including cy- linder in cwt.	8,830	4,180	4,180	4,050	4,700	4,196	3,720	5,192	5,180	5,814	4,944	10,100
Distance sunk under above weights without further excavation, in ft.	8.25	2.25	2.66	1.91	1.33	2.28	4.50	5.50	6.58	7.25	6.27	0.50
Area of surface of cylinder below ground in sq. feet	493	483	518	566	586	535	1,112	707	615	1,724	1,169	2,129
Weight per square foot of surface exposed to friction . . in cwt.	7.77	9.64	8.06	6.14	7.06	7.78	8.84	7.34	8.40	8.87	2.85	4.44

CAST-IRON CYLINDERS.

	D.				E.				F.				G.				H.			
	Pier 27. Down- stream Cylinder.	Pier 28. Up- stream Cylinder.	Pier 29. Down- stream Cylinder.	Average Results.	Pier 27. Down- stream Cylinder.	Pier 28. Up- stream Cylinder.	Pier 29. Down- stream Cylinder.	Average Results.	Pier 27. Down- stream Cylinder.	Pier 28. Up- stream Cylinder.	Pier 29. Down- stream Cylinder.	Average Results.	Pier 27. Down- stream Cylinder.	Pier 28. Up- stream Cylinder.	Pier 29. Down- stream Cylinder.	Average Results.	Pier 27. Down- stream Cylinder.	Pier 28. Up- stream Cylinder.	Pier 29. Down- stream Cylinder.	Average Results.
Depth, as above . in feet	5.91	5.00	8.66	4.86	17.32	13.50	10.50	13.77	23.32	23.00	19.82	22.06	36.00	33.00	34.00	34.68	61.59	58.59	52.59	57.59
Sinking weights, as above in cwt.	648	940	660	749	1,064	660	652	792	1,188	1,220	1,213	1,207	1,958	2,891	2,023	2,291	5,038	5,120	5,040	5,066
Distance, as above, in feet	2.75	4.00	3.91	3.55	8.00	8.50	7.25	7.25	13.58	10.00	14.00	12.58	13.00	15.33	14.00	14.11	4.41	4.41	3.41	4.08
Area, as above in . sq. feet	149	128	92	122	435	389	264	346	586	578	498	554	927	829	864	870	1,548	1,472	1,322	1,447
Weight, as above . in cwt.	4.86	7.48	7.17	6.84	2.44	1.95	2.45	2.28	2.03	2.11	2.43	2.19	2.10	8.48	2.36	2.65	3.25	3.48	3.05	3.26

cast-iron cylinders, as well as the different characters of their surfaces, has led to the separation of the two into different Tables to facilitate comparison of the results. As there were almost identical results with each of the two cylinders forming one pier, only one of each pair has been noted in these Tables, which thus give the mean results of five of the brick cylinders and three of the cast-iron cylinders.

In passing through the first strata of fine sand and of gravel, the highest frictional resistance was met with, both in the brick and in the iron cylinders, the greatest being 9·64 cwt. and 7·48 cwt. per square foot of surface below the ground respectively, whereas no friction approaching this was encountered lower down in the stiff mud and blue clay. Taking, however, the average of each set of Tables, it appears that a resistance of 5·84 cwt. per square foot of surface exposed to friction was met with in sinking the brick cylinders to a depth of 56·80 feet, and of 3·34 cwt. per square foot of surface in sinking the cast-iron cylinders to a depth of 57·59 feet, the pressure being greater upon the cylinders having the larger diameter. It is however uncertain to what extent the nature of the materials of the cylinders affected the frictional resistance.

In any case it appears a fair conclusion that side friction is worth taking into consideration when determining the diameter and depth of cylinders, suitable for sustaining given loads, and sunk in strata of ascertained character; and that such consideration may turn the scale in favour of either small cylinders sunk to a considerable depth, or larger cylinders sunk to a less depth, according to local circumstances, and that the most economical results might follow the adoption of the latter system. It is not however to be assumed that the values found to exist in the case of the Rokugo bridge should be taken in practice as correct for purposes of calculation. The subject has not, so far as the Author is aware, been generally considered in estimating the stability of foundations of this description, and further observations, and a careful comparison of results, will probably show its importance.

The contents of this Paper have been compiled by the present engineer in charge, Mr. E. G. Holtham, M. Inst. C.E., from memoranda and notes left by the late Mr. Theodore Shann, a young engineer who was ready and fertile in resource, and of much promise.

The communication is illustrated by drawings, from which Plate 4 has been engraved.

[APPENDIX.

APPENDIX.

ON THE FLOOD OF SEPTEMBER 16TH, 1878, IN THE ROKUGO RIVER.

This was the highest flood that had occurred for many years, the level attained being identical with that assumed, from inquiry of persons in the locality, as extreme flood height; as to the correctness of which there had been some doubt, owing to its being above the top of the river bank.

The rainfall as observed at Tokio (at a point about 98 feet above the sea), was, on eight days between the 4th and 13th of September, equal in the aggregate to a depth of 7·81 inches, and on the 15th alone above 5 inches additional fall took place. It is probable that this rainfall was largely exceeded over great part of the basin of the Rokugo. The river, which had been but slightly increased in volume up to the 15th, began on the afternoon of that day to rise rapidly, and in the night carried away the road-bridge crossing the river about $\frac{1}{2}$ mile below the railway, and burst the banks at several points both above and below the bridge, causing considerable loss of life and destruction of houses. At 8 A.M. on the 16th, when the Author arrived at the bridge (after wading for more than a mile through flood-water passing over the low railway embankment north of the river, the passage of trains being stopped by the washing away of ballast), the flood was pouring over the top of the river bank on the south side, just above the bridge; and at pier 28 the water-level attained the necking of the cylinder cap. There was an apparent difference in height of 18 inches between the water-level at this point, which is the centre of the channel, and that at the northern end of the flood-openings. The flood had however by this time fallen nearly a foot below its greatest height, which was attained about 4 A.M., as observed by the platelayer residing near the bridge, whose house on the top of the river bank narrowly escaped destruction. The water fell continuously throughout the day, although about 3 inches of rain were measured on the 16th, and in about five days the river resumed its usual condition.

No damage was done to the bridge, although there was considerable scour around pier 1, extending to within 6 inches of the bottom of the concrete; and a portion of the down-stream slope of the embankment within the flood-bank slipped away, but was easily repaired with stakes and fascines.

As a precaution against a recurrence of the scour, the whole space under the first two openings on the north side, to a width of 60 feet, has been pitched with large stones, retained by a row of piling on either side of the bridge, at the level of the top of the sheet piling around the piers, which it is believed will effectually withstand any future possible rush of water at this point, around the end of the embankment within the flood space.

(Paper No. 1704.)

“New York Elevated Railroads.”¹

By ROBERT EDWARD JOHNSTON, M. Inst. C.E.

THE question of a more expeditious means of communication between the business and residential quarters of New York than the accommodation afforded by the ordinary omnibus and tramway cars has for some years occupied the attention of its citizens and enterprising capitalists. This want has been felt more acutely in New York than in any other of the large cities of the United States, owing to the fact that Manhattan Island, on which the city is built, is extremely narrow in proportion to its width. The average width is about 2 miles, and the mean length 13 miles. The limits of the city include not only the whole island of Manhattan, but also a portion of the main land to the north of the Harlem river, forming the 23rd and 24th Wards of the City, covering an area of about 19 square miles, and embracing a population of 41,600, the population of the entire city being 926,300 according to the last census. The business quarter is at the southern end of the island. Where the junction takes place between the East and Hudson rivers, on the frontage for a distance of about 1 mile along each river, are situated the various jetties belonging to the transatlantic steamship companies, and those of the various railroad companies having their termini in Jersey City, on the right bank of the Hudson; also the ferries for connecting Jersey City, Hoboken, Staten Island, and Brooklyn, with New York. The residential quarter extends to the neighbourhood adjacent to the Central Park. From this point to the extreme north of the island, a distance of about 8 miles, buildings are sparse, owing to the inadequate means of communication between the north and south ends of the city prior to the adoption of elevated railroads.

As far back as 1867 an attempt was made to improve the then existing means of transit from the residential to the business centres of the city, by the construction of an elevated railroad. This experimental railroad was worked by a wire rope and sta-

¹ On this subject the following may also be consulted: *Engineering News* (of New York), vol. vii., pp. 29-31, 69, 70; and *Engineering*, vol. xxix., pp. 10, 50, 54, 208, 213, 240.

tionary engine ; but, as might have been anticipated, this means of locomotion proved unsatisfactory, and led to the financial embarrassment of the company. In 1872 the railroad passed into other hands, and the present New York Elevated Railroad Company was formed. The advisers of the company, profiting by past failure, recommended the abandoning of stationary engines as the motive power, and the substitution of small four-wheeled locomotives.

From 1866 to about the year 1874 the question of a further extension of railroad accommodation received much consideration, and the question of the advantages of underground railways over elevated ones was largely discussed. In the month of June, 1875, an Act was passed to give additional effect to the existing laws regulating the construction of railways, by the legislature of the State of New York, and empowering the mayor of any city in the State of New York, "on the application of fifty reputable householders and taxpayers," to appoint a commission, consisting of five members, to determine whether there was need of a railroad in the city.

Immediately on this Act becoming law the Mayor of New York was called upon, under the terms of the Act, to appoint a commission ; and this he did on the 1st of July, 1875. On the 6th of October of the same year the Commissioners reported unanimously in favour of elevated railroads, after having had before them the promoters of under-ground and over-head schemes ; and at the same time, in accordance with their instructions, they laid down the routes they considered most desirable for the railroads, having regard to the convenience of the public and the question of injury to property fronting the streets along which it was proposed to construct the railroad. It was on the recommendation contained in the report of the Commission that the present elevated railroads have been constructed.

At the present time two elevated railroads are open for traffic in the city ; one called the New York Elevated Railroad, and the other the Metropolitan Elevated Railroad. The lines of both these companies are now leased to a third company called the Manhattan Railway Company ; this company operates and manages the entire system of elevated lines in the city. The former has its southern terminus at the South Ferry, and from this point diverge the lines which traverse the eastern and western sides of the city, and their course may in general terms be described as follows:—

The eastern branch, after traversing Front and Pearl Streets,



reaches the New and Old Bowery, at which point the short spur to the City Hall and Post Office connects with this branch ; it then follows the course of the Old Bowery to the commencement of the Third Avenue, along which it then passes to the Harlem River at One Hundred and Twenty-ninth Street. At East Thirty-fourth Street there is a short branch to the Long Island Railroad Ferry, and also one at Forty-second Street, to connect with the Grand Central Depôt of the New York Central and New Haven Railroads, Harlem and Balm Railroads, and Hudson River Railroad.

The western branch has the same point of departure as the eastern branch at the South Ferry, passing over Battery Park to Greenwich Street, running along its entire length to its junction with Ninth Avenue, along which it passes, until it joins the Metropolitan railroad at Fifty-third Street. From this point to where West Eighty-third Street crosses the Ninth Avenue the line is owned jointly with the Metropolitan Company.

The West Metropolitan branch commences at a connection with the Ninth Avenue line in Greenwich street, near the Northern side of the Battery Park, and, after passing along West Broadway, South Fifth Avenue, it curves round into Amity Street, and then into Sixth Avenue, which it traverses until it reaches the terminus at the Central Park at Fifty-ninth Street. A little to the south of this terminus there is a junction which carries the line to the left along Fifty-third Street, where, by another junction, a connection is made with the west branch of the New York Elevated Railroad on the Ninth Avenue. From this point to Eighty-third Street the line, as before-mentioned, is used jointly by both companies.

At Eighty-third Street the Metropolitan Railroad commences, and continues along the Ninth Avenue to One-hundred-and-tenth Street, which it traverses to the intersection of that street with the Eighth Avenue ; it then passes along this avenue to the terminus at the Harlem river, at One-hundred-and-fifty-fifth Street, near High bridge, at which point a connection is made, by means of a bridge over the Harlem River, with the New York City and Northern Railroad.

The East Metropolitan branch follows generally the route of the First and Second Avenue. Its terminus is at the Harlem river, at One-hundred-and-twenty-ninth Street.

Having given a general outline of the course of the various railroads, it is intended to describe the main features of the superstructure and the modifications which have been resorted to with a view of reducing to a minimum any inconvenience likely to arise

from constructing an overhead railroad in the streets of a city with crowded thoroughfares.

On the New York Elevated Railroad the method adopted for carrying the line along the avenues and streets may be divided into three systems.

1st. That where the supports are placed in the line of the curbstones, with the head of the column spread out to receive the main or longitudinal girders. This mode of construction is adopted in streets where the occupations carried on in the adjacent buildings are not affected by the frequent passing of trains, or in those instances where the streets are of considerable width and too crowded to admit of supports being placed in the roadway. (Fig. 2.)

2nd. In those instances where the cart and other wheel traffic is of a crowded nature, and supports in the roadway would be inadmissible, or where the streets are narrow, and it is desirable to remove the railroad as far as possible from the buildings, columns are placed in the line of the curbs, and connected at the top by transverse girders, which in turn carry the ends of the main girders on which the trains run. (Fig. 5.)

3rd. When the width of the roadway and the nature of the traffic will admit of supports being placed in it, they are spaced at a distance of 23 feet 6 inches from centre to centre, measuring in a direction at right angles to that of the street, and are connected at the level of the longitudinal girders with a neat arched or latticed bracing to steady the structure. (Fig. 6.)

Foundations for Main Columns.—As the columns perform important functions in a system of elevated railroads of the nature described in this Paper, great care has been devoted to them and the foundations on which they rest. In all cases, with the exception of those in which rock is met with, the ground is excavated to a depth of 7 feet below the surface of the street, and the bottom covered with a coating of mortar concrete 4 inches in thickness; on this is placed two flags, 3 feet wide and 7 feet long, varying in thickness from 4 to 8 inches, and a space of 1 foot is left between the flags in the direction of their width so as to make the foundation 7 feet square. On the foundation thus prepared the brickwork which forms the body of the work is commenced. This is 7 to 9 feet square at the bottom, tapering upwards to 4 feet square at the top. The depth of the brickwork is 4 feet. The surface of the pier so formed is levelled off with a bed of mortar, and on this the cast-iron base of the column is laid without the insertion of any stonework below the base and brick-

work. This base, which weighs about 3000 lbs., is secured to the pier by four holding-down bolts, 2 inches in diameter, which extend from the top to the bottom of the pier, large cast-iron washers, 11 inches square, being placed under the flags which form the base of the pier. The mortar is made from ground "hydraulic cement" mixed in the proportion of 1 part of cement to 2 parts of clean sharp sand, the cement being of such a quality when mixed in the above proportion as shall be capable of bearing a tensile strain of 50 lbs. per square inch after thirty minutes exposure to the atmosphere and twenty-four hours in water.

In those instances where a reliable foundation could not be met with at the depth mentioned, piling was resorted to. This was composed of nine piles, 12 inches in diameter, capped with timbers 9 inches wide by 12 inches deep, secured to each pile with an oaken or a locust wood trenail $1\frac{1}{2}$ inch in diameter and 16 inches long. Over this was laid a flooring of 5-inch spruce or yellow pine planking, spiked with two wrought-iron spikes 9 inches long by $\frac{5}{8}$ inch diameter at each crossing. The piles were made from oak, spruce, or chestnut wood.

Main Columns.—The cast-iron base into which the wrought-iron portion of the column is fitted is 3 feet 4 inches square and 2 feet $4\frac{1}{2}$ inches deep, with ten stiffening fins extending nearly the full depth of the casting. The column is fixed in the casting by iron cement caulking, and further secured by four to six steel dowel pins, drilled and reamed to a perfect fit, in slightly tapered holes, about $1\frac{1}{2}$ inch in diameter, which appears to make a secure connection, as the Author could find no trace of movement of the column in the casting.

The columns, when placed on the line of the curb, and connected at the top with cross-girders or bracing, are made with two 15-inch channel-irons weighing 150 to 200 lbs. per yard, with locks varying in thickness from $\frac{1}{2}$ to 1 inch, connected together with lattice bars $3\frac{1}{2}$ inches wide by $\frac{5}{8}$ inch thick, set at an angle of 45° , and riveted to the wings of the channel-irons by rivets $1\frac{5}{8}$ inch in diameter; the length of these bars being such as to make a column 15 inches square.

When the columns are isolated they are 15 inches by 18 inches wide, the greater width being placed transverse to the course of the railroad, so as to give additional stability in this direction. At a distance of 5 feet from the head, the column is widened to 5 feet, to receive the ends of the main girders, which are placed 5 feet apart from centre to centre. The bracing in the lower part of the column, up to the point where it commences to

spread out, is made with bars 4 inches wide by $\frac{1}{2}$ inch thick; in the upper portion two bars of the same scantling have been used. The upper ends of the channel-iron or head of the column, are united with two plates 5 feet long, 1 foot to 2 feet deep, and $\frac{7}{16}$ inch thick, the ends being cut to the sweep of the channel-iron. To these plates are attached two angle-irons, 6 inches by 4 inches by $\frac{1}{2}$ inch, to which in turn are riveted the top plates of the column, 1 foot 6 inches by 2 feet by $\frac{5}{8}$ inch thick (Fig. 2), on which rest the girders which form the railroad and carry the permanent way on the upper flange. These columns mostly vary in length from 18 to 21 feet; but when these lengths are exceeded they are united across the street, so as to give them the requisite amount of steadiness.

Longitudinal or Main Girders.—The girders generally adopted for this line vary from 37 to 44 feet span. With the exception of those instances where longer ones are required at the intersection of the streets with the avenues, the depth varies from 2 feet 9 inches to 3 feet 6 inches, the top and bottom booms for the shorter spans being composed of two 6 inches by 6 inches by $\frac{9}{16}$ inch by two 6 inches by 6 inches by $\frac{1}{2}$ inch angle-iron respectively, as shown in Figs. 1 and 4. The longer ones are reinforced by plates of such length, width, and thickness as may be required to afford the necessary sectional areas required by the spans. The booms are united by bracing of single triangulation, made of angle-iron, those at the ends being 6 inches by 3 inches by $\frac{7}{8}$ inch, and the intervening bars 4 inches by 3 inches by $\frac{7}{8}$ inch attached to the booms by rivets $\frac{7}{8}$ inch in diameter. The length of panel is made as nearly as possible 4 feet 8 inches long, as this length is found to be the most suitable distance, seeing that the upper boom, owing to the formation of the permanent way, has to act as a girder between the apices of the web bracing. The girders are in all cases placed at a distance of 5 feet apart from centre to centre; and to thoroughly brace the entire superstructure well together four vertical frames are inserted in each span. The top and bottom members of these frames are made with 4 inches by 4 inches by $\frac{7}{8}$ inch angle-iron, the diagonal braces being two 3 inches by 3 inches by $\frac{7}{8}$ inch angle-iron. The top and bottom booms are still further braced together with horizontal bracing, the upper bracing being made with 3 inches by 3 inches by $\frac{3}{4}$ inch angle-iron, and the lower with 2 $\frac{1}{2}$ inches by 2 $\frac{1}{2}$ inches by $\frac{3}{4}$ inch angle-iron attached to the girder with $\frac{5}{8}$ inch rivets. The girders are fixed to the columns at one end, but are free at the other end, oblong bolt holes being provided to admit of expansion and contraction.

Transverse Girders.—These are about 28 to 45 feet long varying with the width of the street, and are riveted to the head of the columns. Fig. 5 represents a girder of 45 feet span with the columns placed in the line of the curb stone, and Fig. 9 shows how the junction between the main and transverse girder is effected.

Permanent Way.—The permanent way is laid on the top boom of the longitudinal girders already described, and consists of a Vignoles Bessemer steel rail of the section shown by Fig. 10, weighing 50 lbs. per yard, and 30 feet long, and $3\frac{3}{4}$ inches deep; the bottom flange is four inches wide, and it is attached to the sleepers by two dog spikes 5 inches long and $\frac{9}{16}$ inch square, one on each side of the rail, so that there are four dog spikes in each sleeper to keep the road to gauge.

The joints are fished with two angle fish-plates 2 feet 1 inch long, weighing 24 lbs. per pair, and approximating to an angle-iron in section. The lower wings extend beyond the foot of the rail, and in them is cut a notch so as to admit of dog spikes being driven into the sleepers to prevent the rails from working down the incline. The fish-bolts are $\frac{1}{2}$ inch in diameter; there are four to each joint. The sleepers are laid transversely to the railway and are made of white oak and yellow pine; their scantling is 6 inches by 6 inches by 8 feet long. They are spaced at a distance of 1 foot six inches from centre to centre, and they are attached to the top booms of the longitudinal girders by a lag-screw 5 inches long and $\frac{3}{4}$ inch in diameter, and by a bolt of the same diameter which is also used for fastening the outside guard-timber to the sleepers, a clip washer being placed at the lower end to grasp the underside of the boom of the girder.

At a distance of 4 inches from the edge of each rail an inside and outside guard-timber is provided and attached to the sleepers by bolts $\frac{3}{4}$ inch in diameter, to prevent the train from leaving the track in case of derailment. The inside guard is 5 inches by 8 inches, and the outside 5 inches by 10 inches. These guard timbers also serve to increase the longitudinal stability of the structure; for, owing to the fact that the girders are free at one end for expansion and contraction, they cannot be depended upon to contribute much to the steadiness of the road under a passing train. On curves the requisite amount of super-elevation is obtained by using sleepers cut on the taper.

The sharpest curve on the main line has a radius of 90 feet, and shortly after leaving the terminus at South Ferry there is a reverse curve of 125-feet radius. The gradients conform closely to those of the street, with the exception of those instances where

the changes are frequent; under these circumstances an approximation is made so as to avoid numerous alterations in the levels of the line. The steepest gradient is 1 in 50 for 800 yards.

Rolling Stock.—The locomotives first adopted for working the traffic of the line were four-wheeled tank engines; all the wheels, which were 3 feet 2 inches in diameter, were coupled, giving a wheel-base of 6 feet. The cylinders were 10 inches in diameter, with a length of stroke of 14 inches; but with the development and success attending the introduction of the elevated railways, greater speed and heavier trains were required to meet the demands of the public. This led to the introduction of heavier engines; and the latest additions have four wheels coupled, placed between the fire- and the smoke-box. In rear of the fire-box there is a four-wheeled bogie cab truck, which carries the cab, water-tank, and coal-bunker. These engines are giving satisfactory results, and so far have proved equal to the working of the traffic under the greatest emergencies.

The coupled wheels are 5 feet 9 inches from centre to centre, and 3 feet 6 inches in diameter. The total weight on the four wheels is $13\frac{3}{4}$ tons. The distance from the centre of the driving wheels to the centre of the truck is 10 feet 1 inch. The truck wheels are 4 feet 8 inches from centre to centre, and 2 feet in diameter. The weight carried by the truck is $5\frac{3}{4}$ tons. The cylinders, which are outside the framing, are 12 inches in diameter, and of 16 inches stroke. The fire-box has a width of 2 feet 10 inches, and is 4 feet 9 inches long. The barrel of the boiler is 6 feet 5 inches long, 3 feet 8 inches in diameter, and contains one hundred and sixty-five tubes, $1\frac{1}{2}$ inch in diameter. The water-tank will contain 600 gallons of water, and the coal-bunker $4\frac{1}{2}$ cwt. of coal.

The cars are of the usual American type, being entered from each end, with a gangway down the centre. They are 45 feet long, 8 feet wide, and seated to accommodate forty-two passengers. These vehicles weigh 12 tons, and are mounted at each end on a bogie truck, the wheel-base being 5 feet, and the distance from centre to centre of the truck 30 feet. The platform at each end of the car is enclosed with an iron railing, a gangway being left to allow passengers to walk the entire length of the train. In the railing, gates are provided for controlling the ingress and egress from the cars to the platform. On the platform formed by two cars there is a conductor, whose duty it is to open and close the gates on the arrival at the station. This arrangement is absolutely necessary, as the railway is only the width of a car body, so that should a passenger attempt to leave the train before it arrived at

the station platform, or get out on the wrong side, he would fall into the street below. The cars are centre-coupled, and the end of the platform is well rounded, so as to give freedom of motion to the train in passing round the sharp curves.

All trains are provided with continuous pneumatic brakes, which give the engine-driver complete control over the train, and this provision enables him to stop it in a short distance. This is the more necessary as the stations are only about $\frac{1}{3}$ mile apart. Hand-brakes are also provided on each car, which are worked when necessary by the guards.

The stations are, when possible, placed at the intersection of the streets, an arrangement which causes the least interference with the light and overlooking of the adjacent buildings from the station. The stations are approached from the street by two flights of steps, one from each footway.

The accommodation provided for passengers at the station is limited, and does not accord with English practice; there is only one room which does duty for booking-office and waiting-room, having about 100 feet of roofing over the platform.

The platforms, as originally constructed, have, owing to the great development which has taken place in the traffic since the railroad was opened, proved inadequate, and have been lengthened and widened; they are now 200 feet long, and 13 feet wide.

Owing to the form of construction adopted, the railroad is open to the street below, and to prevent oil and water falling upon people passing under it, while the train is standing at the station, a tray is suspended immediately under the girders, and of sufficient length to ensure an engine, when standing at a station, to be over it, and for the same reason the ash-pan under the fire-box is so arranged as to ensure that no cinders shall be shaken from it by the motion of the engine.

There was in operation, on the 30th of November, 1879, a length of $34\frac{1}{2}$ miles of elevated railroad in the city of New York. Some idea of the use made of it by the public may be gained from the fact that about 165,000 passengers are carried per day; but the largest number carried on one day has been 274,000. The trains in the morning and evenings, when men are going to and from their business, run every two minutes; and in the quieter part of the day they run with intervals of from four to five minutes between the trains. The cost of working the railroad is about 63 per cent. of the gross earnings, including charges of all descriptions.

The fares from 5.30 A.M. to 8.30 A.M., and from 4.30 P.M. to

7.30 P.M., are 5 cents for any distance, and during the remainder of the day 10 cents for any distance.

The following gives the cost of a mile of double road, including stations and rolling stock, reckoning the dollar at 4s. :—

Foundations, column girder, superstructure, and per-	2
manent way	57,696
Stations	12,000
Rolling stock :—Five locomotives	4,000
Twelve carriages	7,680
<hr/>	
Total cost per mile for railroad, stations and	
equipment	81,376
<hr/>	

For a railroad passing through the heart of a city these figures are exceptionally small ; but this is accounted for by the fact that no payment has been made for way leave along the streets, nor has any compensation been paid to the frontagers for the unquestionable damage they have in a number of instances sustained by the railroad being constructed to within a few feet of their property ; and this is further aggravated by the form of construction adopted, the railroad being on a level with the first floors of the buildings abutting on the street. In the residential quarters of the city in those thoroughfares traversed by the railroad rents have, in many instances, been depreciated to the extent of 50 per cent. without compensation being paid for the injury done.

This is contrary to the mode of procedure adopted under similar circumstances in this country ; but in America the laws of the State of New York do not provide the owners with any remedy for the depreciation their property may sustain by the construction of these elevated railroads in the manner described.

The Metropolitan Elevated Railroad is similar in construction to that adopted for the New York Elevated Railroad, with the exception that in some instances, on the first section of the road constructed, the railroad runs between the girders, instead of on the top ; and in no instance is the railroad supported upon one column ; so that, when the street is not of sufficient width to admit of the supports being placed in the roadway, they are fixed in the curb line, with a cross girder to carry the main girders, which are placed in the centre of the streets, 24 feet apart.

The columns on this line are of two descriptions ; in one instance they are made with two 9-inch channel-irons, weighing 42 lbs. per lineal foot, connected together with two plates, 16 inches wide and $\frac{5}{8}$ inch thick ; the other is known as the Phoenix column, being formed from six segments, so that when riveted together

they make a column $11\frac{1}{2}$ inches in diameter, with six projecting fins on the outside. The thickness of metal is $\frac{3}{4}$ inch. On the lower end of these columns is riveted a spherical casting, made to a 9-inch radius, which rests upon a surface formed to a corresponding curve in the bottom of the casting, which constitutes the base of the column, the object being to ensure a uniform bearing between the end of the column and the base in the event of the latter not being set exactly level. After the column has been fixed in place and plumbed, it is wedged in this position, and the space between the column and the casting is filled in and secured with the usual rust-joint composition.

In One-hundred-and-tenth Street these columns are 65 feet in length, and, owing to the great elevation of the railroad at this point, and to give the requisite stability, they are braced into groups of four, in a square, with girders reaching from group to group.

With these exceptions, the same system is generally adopted by the two elevated railroads in New York.

In conclusion, the Author desires to avail himself of this opportunity of tendering his best thanks to Mr. Walter Katté, the Engineer-in-Chief, and Mr. Stirling, Local Superintendent of the New York Elevated Railroad, for the information contained in this Paper. His thanks are also due to Mr. F. W. Smith, the Assistant Engineer of the railroad, who accompanied him on his inspection of the works which have just been described.

The Paper is accompanied by several tracings, from which Plate 5 has been prepared.

APPENDIX.

THE following is an extract from Mr. Katté's specification so far as relates to the quality and tests prescribed for wrought iron used in the construction of the New York Elevated Railroad :—

“All the material used for the columns, girders, bracing, &c., shall be of wrought iron (except when otherwise specially authorized) and shall be of the following general character—tough, highly fibrous, uniform in texture, and of a quality in every respect equal to that used in first-class American iron railway bridges. In its manufacture no old or scrap iron is to be used; test pieces, selected at random by the engineer, and cut from any of the channel bars, angle-iron, or plates furnished for this work, shall show an ultimate tensile strength of not less than 50,000 lbs. per square inch of original sectional area before fracture, and an elastic limit of not less than 25,000 lbs. per square inch of same sectional area, with an elongation before fracture of the test specimens of not less than 15 per cent., measured upon a tested length of 8 inches, and a reduction of area at the point of fracture of 20 to 25 per cent.”

“Test specimens shall also be capable of being bent cold to a 90°-angle, on a curve having an outside radius equal to twice the thickness of test piece, without showing any crack or break in the fibre of the iron. All rivets shall be made of double refined iron, having an ultimate tensile strength of 60,000 lbs. per square inch, and be capable of being bent double when cold, so that the sides shall be in contact without showing any cracking or breaking of the fibre of the iron.”

(Paper No. 1823.)

"Light Scaffolding."

By JOHN CUNDY, Assoc. M. Inst. C.E.

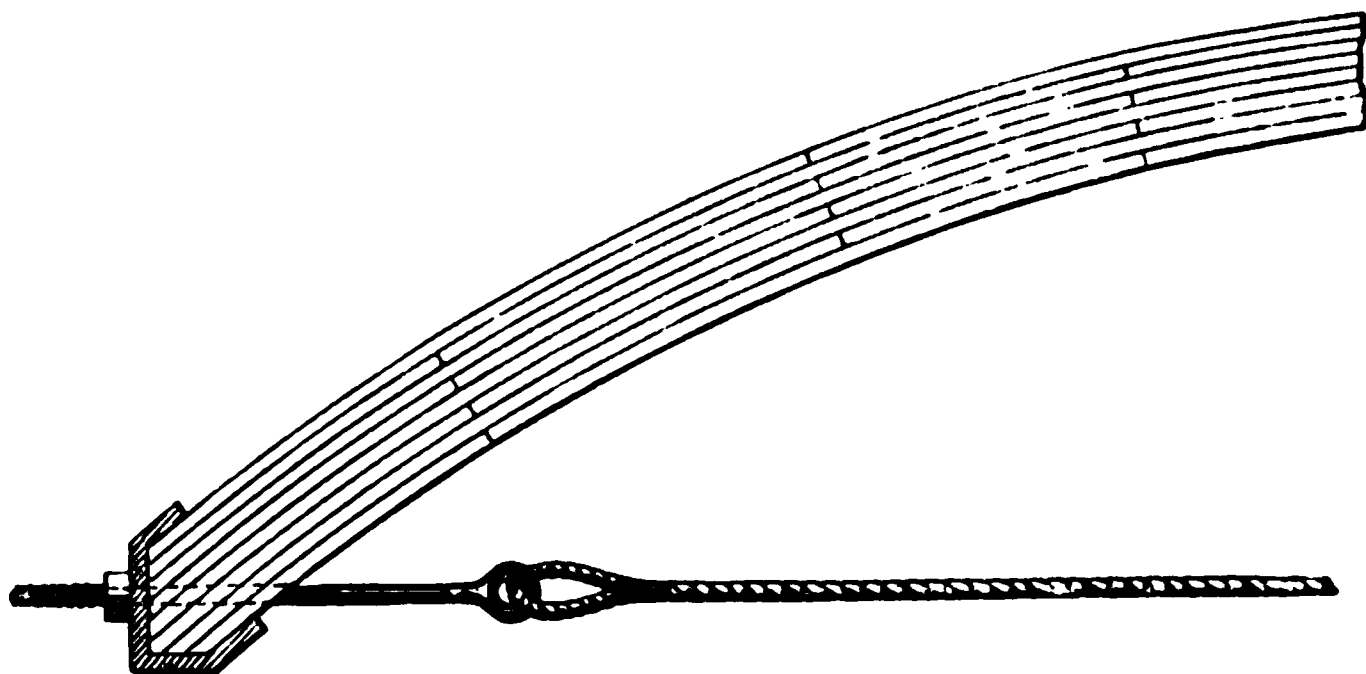
IN the autumn of 1878 the ironwork of the railway terminus at the New Central Station, Manchester, was sufficiently advanced to enable the contractors, Messrs. A. Handyside and Company, Limited, of Derby, to proceed with the roofing in. The sub-contract for this work having been entrusted to the Gloucester Wagon Company, Limited, and successfully carried out by the steam joinery works of that company, the Author, then the superintendent of that department, received instructions from the engineers of the Cheshire Lines Committee to provide a light and convenient scaffolding that would enable the various trades to be carried on with safety, and at the same time to afford a ready means of access to all parts of the roof for the necessary inspection by the engineering staff, one of the conditions being that a width of about 100 feet in the centre of the station should be at all times free for use as siding room for carriages, and other requirements of the railway company.

Much has been written on the subject of timber scaffolding, and examples are not wanting of clever and scientific structures of this class designed to facilitate the erection of iron buildings, such as the various international exhibitions of this and other countries, and likewise the more recent railway termini, such, for instance, as the St. Pancras in London, St. Enoch at Glasgow, and lastly, the Central Station at Manchester. All the scaffolds used in the construction of these works have been designed on the same principle—massive framework, calculated to bear the heavy machinery and materials necessary for their construction. It will be evident that these solid structures cannot be made available for the lighter work of the roof, consisting of filling in between the iron ribs with glazed ridge and furrow roofing, the lead and zinc work, boarding, slating, and lastly, the painting and decorating of the whole fabric; therefore some independent means must be provided by the contractor, and as the outlay of the work to be done is of comparatively small value, and of shorter duration than the main building, economy of cost and facility in manœuvring, consistent with stability, must be the chief object of the designer; the structure should be as much labour-saving as it is possible

to make it, and the outlay should not exceed 5 per cent. of the contract sum.

The Author, after due research for a precedent, found that the methods hitherto adopted had nothing to recommend them. A plan made use of by Messrs. Handyside for this class of work at the St. Enoch station at Glasgow, fulfilled many of these requirements, and a brief description of this scaffolding will not be out of place. It consisted of three ribs composed of battens 7 inches by 1 inch laid one upon another breaking joint, and forming a solid section of wood 8 inches deep by 7 inches wide, and about 80 feet long. Each batten was securely nailed, and, when finished, was held in the curved form by a wire-rope. The ends of the battens fitted into cast-iron shoes, through which the wire-rope was secured by a screw-bolt with strong nut (Fig. 1). This bow and string was

FIG. 1.



further strengthened by timber cross-ties and braces, and when in position formed the framing of a platform corresponding to the curve of the iron ribs of the building. This structure was mounted upon light travelling stages in the usual manner. In practice, however, this method proved somewhat unsteady, and its reputation with the workmen was not such as to warrant a repetition of the same construction for the staging of the Manchester roof.

The Author, having had experience in the construction of light timber roofs, especially wooden models of the well-known iron lattice, bow and string girder bridges, which have been successfully applied to temporary buildings of wide spans, and which were introduced many years ago by the Messrs. Ellis of Liverpool as the framework for their patent roofing felt, determined upon adopting this method for the bridge of the travelling stage in question, the span of which could not be less than 95 feet in the clear of its supports. The construction is illustrated in Plate 6.

It consists of three ribs, or wooden girders of the same radius as the curve of the iron framework it was intended to work under; each of these sections was composed: first, of the bow of three thicknesses of spruce battens 7 inches by 2 inches; secondly, the string, also of three thicknesses of pitch pine 7 inches by 2 inches, selected free from defects, with the trellis-work intersecting these. Each trellis piece was of selected spruce 5 inches by 1 inch, the whole securely held together by $\frac{1}{2}$ -inch bolts and nuts forming a complete arc, the chord of which measured 130 feet, with a versed sine of 26 feet. The three ribs thus constructed were placed in position 9 feet apart, and rigidly held together by light cross-frames and joists, and secured by $\frac{3}{4}$ -inch tie-rods. The getting together of this light structure was accomplished without trouble; the only difficulty experienced was raising from the ground to an erect position the first segment, which from its flexibility required care and skill on the part of the workmen; its weight was barely 3 tons. The weight of the complete bridge, when ready for lifting, was a trifle over 10 tons. The height of the Central Station, from the underside of the main ribs to the rail level, is 89 feet, with a clear span of 210 feet. To raise the bridge it was necessary to make use of the building. The engineers, consenting to a weight of 10 tons being lifted by blocks secured to the main ribs, the operation was quickly accomplished by picking up the framework in six places, and suspending the bridge to within 3 feet of the iron-work of the roof. The two travelling stages were now run under, and the structure was firmly secured at a height of 60 feet from the rails. These stages were of light framework, well braced, and built upon strong under-frames of Swedish timber, provided with six cast-iron wheels and pedestals. The whole scaffold could then be moved along its double line of railway of 15-foot gauge by three men to each under-frame. When complete and in working order the structure, exclusive of the wheels, weighed 78 tons. A flight of easy steps from story to story of one of the stages gave access to the lower platform, or string of the bridge, which was used as a general workshop, with tool house and stores. The whole of the lead and zinc work was cut and fashioned on this platform. The top of the bridge was covered in with $1\frac{1}{2}$ -inch flooring, and formed a platform, 25 feet wide, for the men employed on the roof, corresponding with the curve of the iron ribs; a space of 3 feet intervened between the platform and underside of the ribs. Owing to the absence of any formula for ascertaining, even approximately, the strength of such a piece of carpentry, some experiments were made at Gloucester that proved its safe sustain-

ing power to be equal to 28 lbs. per square foot, or a weight distributed of about 46 tons; but at no period during the eighteen months it was at work was a greater weight in men and materials than 15 tons placed upon the scaffold. During all the circumstances of the work, and often subjected to high winds, the staging remained steady, the men employed having entire confidence in their safety. It was once found necessary, by the requirements of the station plan, to shift the position of both stages, and in another instance to shorten it by the depth of the station platform, over which it had to be run; these operations were easily done without accident of any kind.

The timber used in its construction was as follows:—

	Cubic feet.
Spruce boards	3,225
Swedish scantling	850
Pitch pine „	500
	<hr/>
Total	4,575
	<hr/>

The prime cost amounted to £545.

The Paper is accompanied by a drawing and sketch, from which Plate 6 and a woodcut have been prepared.

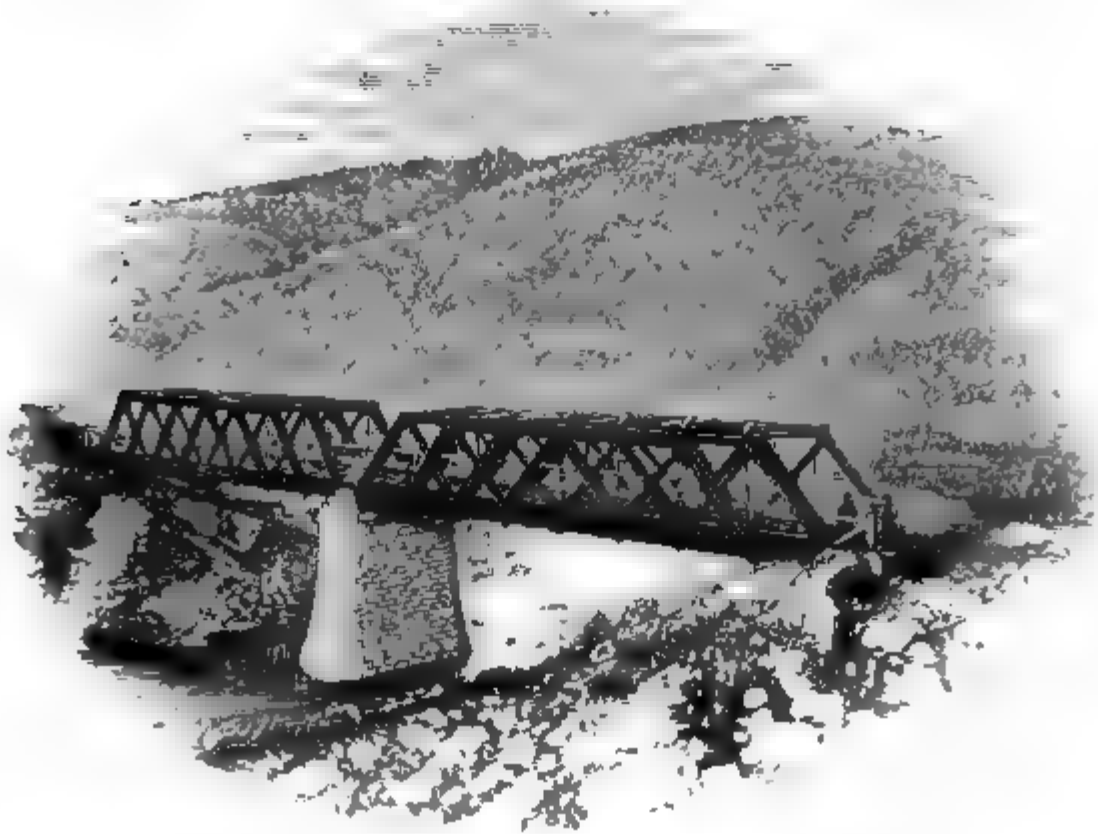


(Paper No. 1821.)

**"Deep Stream Bridge, Taieri County, Province of Otago,
New Zealand."**

By ROBERT HAY, Assoc. M. Inst. C.E.

THE Deep Stream bridge is constructed on the main road to the interior of the province, at a distance of about 40 miles from Dunedin. It is a type of the ordinary road bridges in the Taieri county, where the spans exceed 40 feet. The bridge is 222 feet in



DEEP STREAM BRIDGE, TAIERI CO., N.Z.

total length, in two spans of 100 feet each in the clear, the roadway being 14 feet wide, and the clear height from the top of the planking to the underside of the top bracing is 13 feet. It is of sufficient size to accommodate the largest wool wagons with covered tilts, which wagons with their load weigh about 5 tons, and are drawn by eight- or ten-horse teams, and constitute the greater portion of the heavy traffic from the up-country stations, although in the more settled districts the bridges are frequently exposed to 8- and 10-ton traction engines.

The design is on the trapezoidal truss principle, constructed with special regard to economy, but of sufficient carrying capacity and dimensions to satisfy all the main requirements. The upper and lower chords are in three flitches, breaking joint and scarfed over filling pieces of ironbark. The bottom chord is composed of three flitches 14 inches by 6 inches, and the top chord of three 12 inches by 6 inches, with a straining piece of three 8 inches by 6 inches under the centre. The suspending rods are in pairs, varying from $1\frac{1}{4}$ inch in diameter at the centre of the span to 2 inches at the end panel. The roadway planking is 4 inches thick, close laid, and spiked down to floor joists 12 inches by 6 inches, spaced 3 feet apart from centre to centre. The abutment sills and corbels are of ironbark, held down by lewis bolts $2\frac{1}{2}$ inches in diameter, 6 feet long, and run with lead.

The pier is built of schistose rock, the only stone obtainable within a radius of 20 miles: it is 33 feet high, and contains 289 cubic yards of block-in-course masonry, set in Portland cement (1 in cement to 2 of sand). The cost completed was nearly £2 per cubic yard.

The weight of the structure is 10 cwt. per lineal foot, and the bridge is designed to carry a load of 100 lbs. per square foot in addition to its own weight, with an ultimate strain on the timber of 1,000 lbs. per square inch, and 10,000 lbs. per square inch on the bolts.

The estimate for the bridge complete was £2,220, or £10 per lineal foot. The tenders, of which there were ten, ranged from £1,752 12s. 6d. to £2,380 14s. 4d., the successful tenderer's prices being nearly £7 per lineal foot for the superstructure.

The timbers used in the construction were New Zealand kauri and Australian ironbark, the latter timber being only used in the sills, corbels, butt-blocks and filling pieces. The quantities of material in the bridge were—kauri, 54,000 feet; ironbark, 7,000 feet; ironwork, 16,400 lbs.; masonry, 289 cubic yards; excavation, 295 cubic yards. The whole of the timber and ironwork were forwarded 20 miles by train to the township of Outram, on the Taieri plain, and thence carted another 20 miles to the crossing of the Deep Stream over a rough country.

The bridge was erected by Messrs. Stevens and Nelson, contractors, under the direction of the Author, the Taieri county engineer.

This type of bridge has been found by experience, besides offering a minimum obstruction to the waterway, to be the cheapest and easiest of construction in remote places where skilled labour is

comparatively scarce, and wages and material more than usually high. Such bridges vary in price from about £4 10s. to £10 and upwards per lineal foot, according to the width of span and height of piers; in some cases where iron cylinder-piers are necessary, the cost per lineal foot has been £22. The wages of the men employed on the work were per day of eight hours—labourers, 7s.; quarrymen, 9s.; bridge carpenters, 12s. to 14s.; blacksmiths, 10s. to 12s. The masons, for dressing and building, were paid by piecework, 14s. 6d. per cubic yard. The prices of materials delivered on the site of the work were, approximately—kauri, 25s. per 100 square feet; ironbark, 35s. per 100 square feet; ironwork, 5s. per lb.; Portland cement, 25s. per cask.

(Paper No. 1826.)

"The Kawarau Suspension Bridge, N.Z."

By HARRY PASLEY HIGGINSON, M. Inst. C.E.

THE lake county of the Middle (South) Island in New Zealand embraces a mountainous district divided by lakes, rocky gorges,



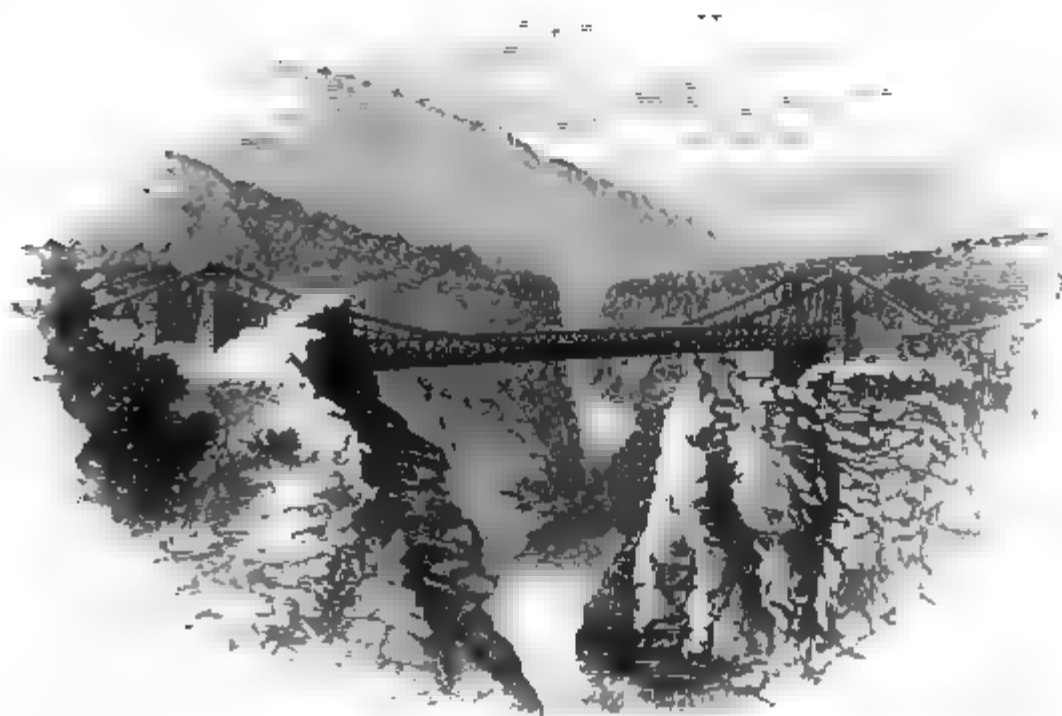
THE KAWARAU SUSPENSION BRIDGE, N.Z.

and rivers subject to floods. Owing to its auriferous character it has for many years been settled by a scattered population, who have latterly brought a considerable area under cultivation. The construction of roads in a country of this description has naturally been costly, entailing the erection of heavy bridge works over rivers which till lately have been crossed by ferry-boats and punts.

The suspension bridge over the river Kawarau, together with about 4 miles of new road, was undertaken by the Lake County Council to improve a portion of the main coach-road between Cromwell and Queenstown on lake Wakatipu, which had always

proved a great obstacle to traffic, owing to the steep gradients and the necessity for maintaining an expensive ferry service over the river. This new portion of the road embraced some heavy rock cuttings, one of which was 50 feet in depth through a projecting spur of the hills; also a bridge 120 feet in length over the river Arrow, another of 60-feet span over the Swiftburn, and other minor works, in addition to the bridge which is the subject of this Paper.

The Kawarau bridge spans the river at a point where it discharges the water of lake Wakatipu, combined with the Shotover and Arrow rivers. It here runs through a deep and rocky gorge for many miles, and is subject to heavy floods. The span is 300



THE KAWARAU SUSPENSION BRIDGE, N.Z.

feet, the platform being 140 above ordinary water-level. The width of the platform is 12 feet between the girders, which is found to be sufficient for a single line of traffic. The versed sine of the cables is one-thirteenth of the span; those at the centre are drawn together 6 feet, forming horizontal as well as vertical curves, so generally adopted in American practice, and which undoubtedly gives great lateral stability to the platform. It also affords greater width between the anchorages, thereby improving the approaches. The violent winds which are frequent in this gorge have but a slight effect upon the bridge. The anchorage tunnels on the north side were driven upon the line of the back stays into a perpendicular face of rock, the roadway being turned under the back

stays and carried up the face of the cliff clear of the anchorages. Upon the south side, owing to the dip of the rock, vertical shafts were adopted, the cables being passed round a curved iron plate, bedded upon a radially-dressed ashlar bearing. The details of the anchorages were the same on both sides (Plate 7).

The four towers were constructed of ashlar masonry, in 18-inch courses, set in Portland cement mortar, some of the stones being upwards of 2 tons in weight. The towers are 3 feet square at the top and 9 feet square at the base. The caps were cut out of single blocks of the hardest stone. Considerable difficulty was experienced in procuring stone sufficiently good for the work, as being a quartzose schist it was very variable in quality.

The cables, which were constructed by the Warrington Wire-Rope Company, are composed of twenty-eight galvanized steel wire ropes $4\frac{7}{8}$ inches in circumference. Each rope consisted of six strands of seven wires each, with a core of hemp. These ropes were arranged in four cables, two upon each side of the bridge. Before shipment from England portions of the wire were tested by Mr. David Kirkaldy, the average result giving a breaking strain of 86 tons per square inch of metal. When twisted into cable form it is estimated that the wire is weakened about 10 per cent., which leaves the ultimate breaking strain at 78 tons per square inch. The factor of safety when the bridge is fully loaded is 4.4. The ropes were originally specified to be $4\frac{5}{8}$ inches in circumference to stand a breaking strain of 67 tons each, but at the suggestion of the manufacturers the size was increased to $4\frac{7}{8}$ inches. The result of the tests proves that the size originally specified would have had ample strength, the factor of safety having been taken at 4, which was considered a sufficient margin.

The wrought- and cast-ironwork was constructed in the colony.

The timber used is the locally termed "red beech" (*Fagus fusca*), which possesses every qualification for bridge-building purposes, being durable, and having a transverse strength equal to English oak. The brace blocks and filling blocks, or keys at joints in the chords, were of Australian ironbark.

In the erection of the cables the ropes were hung over, stretched, and adjusted to correct length separately, a correction being allowed for variation in temperature; the whole was completed in six working days. The following mode was adopted:—

One end of the rope was first passed round an anchor pulley and tightly served with fine wire; it was then fixed into its permanent place in the vertical shaft, hauled across, and the other end passed

round the corresponding anchor pulley fixed into its permanent place upon the opposite side; an ordinary block and tackle was then attached to the free end, and by the help of a double-purchase winch the rope was hauled taut till the deflection in the centre of the span was exactly 6 feet, and left in that position for twelve hours, the strain amounting to nearly 3 tons. It was then lowered, or rather let out, for a length corresponding to the difference between what was necessary for a 6-feet deflection and the permanent deflection of 23·08 feet, when it was fixed by the attachment of clips tightly screwed up.

The anchorages and towers not being in a direct line, owing to the horizontal curve formed by the cables, a temporary staging was erected at the outer side of the towers upon that side of the river where the hauling was effected. The ropes were passed over this stage, which corresponded in height with the saddle-plate upon the towers, next were all stretched side by side, permanently fixed in the anchorage, and then one by one lifted by an ordinary derrick crane and placed in their permanent positions.

By this process the length of the rope was measured while sustaining a strain which entirely removed all tendency to twist or kink, a tendency inseparable from ropes that have been long coiled up. In order also to ensure the rope being tight round the anchor-pulley before being clipped, the weight of one of the tightly-strained adjoining ropes was added to the one being fastened by simply clipping them together. When the full weight of the structure came upon the ropes they all hung correctly in their respective positions and appeared to be equally strained.

It was thought by the Author that the strain applied would have been sufficient to fully stretch the ropes, and that no further elongation would take place from the effect of the permanent load. When however the bridge was completed, the intended camber of 12 inches was found to have been reduced to 9 inches, which for the sake of appearance is ample. This camber has been permanently retained, subject of course to variations in temperature. Before the completion of the work it was found impossible to keep the vertical shafts free from water; they were therefore subsequently filled with Portland cement concrete.

The locality was not conducive to cheap work, being in the centre of the Otago gold-fields, where wages are generally from 30 to 50 per cent. higher than elsewhere. The cost of hauling the material also formed a considerable item, there being 175 miles of railway, 25 miles of water, and 12 miles of road over which it had to be conveyed. The actual cost of the bridge, ascertained from

252 HIGGINSON ON THE KAWARAU SUSPENSION BRIDGE, N.Z. [Selected
careful accounts kept during the progress of the work, was as
follows :—

	£.
Excavation in foundations, shafts, and tunnels	416
Masonry in cement mortar	2,074
Concrete	67
Timber fixed in place "	785
Ironwork "	635
Steel-wire cables fixed in place	1,110
Painting	136
Plant	150
Total actual cost	<u>5,373</u>

This sum does not include anything for contractor's profit or
for engineering management.

The scale of wages paid on the work was: carpenters per
diem, 15s.; masons, 15s. to 20s.; and labourers, 10s. to 13s. 4d.
The Portland cement cost 45s. per cask delivered.

The designing and carrying out of the work was entrusted to
the Author, who was ably assisted by Mr. A. R. W. Fulton, Assoc.
M. Inst. C.E., and Mr. Walter C. Edwards, Stud. Inst. C.E., who
were in immediate charge.

It may be remarked, in conclusion, that for local reasons, the
work was laid out, and the designs and specifications were made,
within sixteen days from the date when the Author received his
instructions. The designs did not suffer from this hurry, as was
proved by the fact that the only departure from the contract plans
was necessitated by the sudden dip of the rock upon the south
side of the river, the consequence of which was that vertical
anchor-shafts had to be adopted in lieu of tunnels as used upon the
north side.

The works were completed and the road was opened for traffic
upon the 30th of December 1880.

ABSTRACT of PARTICULARS.

Span from centre to centre of the towers	300 feet.
Versed sine, $\frac{1}{4}$ of span, or	23·08 "
Width of platform between the girders	12 "
Dead weight of the structure	110 tons.
Live load (at 100 lbs. per square foot)	160 "
Total load possible	270 "
Material of which the cables were composed	Steel wire, galvanised.
Sectional area of metal in the cables	25·9 sq. inches.
Ultimate strength of the cables	2,016 tons.
" strain on the cables per square inch of metal	78 "
Maximum possible strain on the cables	459 "
" " " per square inch of metal	17·7 "
Factor of safety	4·4

The Paper is illustrated by one tracing, from which Plate 7 has
been engraved, and by two photographs, from which the woodcuts
have been produced.

(*Paper No. 1833.*)

“Lancaster Waterworks Extension.”

By JAMES MANSENGH, M. Inst. C.E.

IN the Session of 1876 the Lancaster Corporation obtained Parliamentary sanction to the extension of their system of waterworks. The Author proposes in this Paper shortly to describe the works carried out, and some points of general interest which arose in the course of their execution.

The water with which the town and neighbourhood of Lancaster, including Morecambe, is supplied, is obtained from springs issuing on the southern flank of the range of hills known as Abbeystead, Lee, Dunkenshaw, and Tarnbrook Fells, forming the highest and most northerly portion of the watershed of the river Wyre. This water is of unusual purity, containing not more than 5 grs. of solid matter per gallon, and is under 1° of hardness on Clarke's scale; it was originally delivered into the town by means of works carried out under the superintendence of Mr. Robert Rawlinson, C.B., M. Inst. C.E., in the years 1851–2.

The first instalment of water was taken from springs on Abbeystead Fell and Grizedale Brook, and was limited under the Act of 1851 to 300,000 gallons per day. As compensation to the mill-owners and riparian proprietors on the Wyre for the diversion of this water to the town, a reservoir was constructed in the main valley a little below the village of Abbeystead to contain 28,500,000 gallons, from which the stored water of floods was delivered in dry weather as required. By an Act obtained in the year 1864 the quantity of water authorised to be taken to the town was increased to 700,000 gallons per day, and in consequence of this additional interference with their rights, the millowners' reservoir had to be enlarged so as to contain 76,500,000 gallons. Again in 1876 the increasing demands for water rendered a further application to Parliament necessary, and an Act was obtained in that Session, under which the Corporation were empowered to take 2,000,000 gallons per day from the springs for the use of the town, and were bound to increase the capacity of the compensation reservoir to 185,000,000 gallons.

The general scheme will be understood by reference to Plate 8,

in which it will be noticed that the works for water supply and those for compensation are entirely distinct, and separated by a distance at the nearest point of about 2 miles. The difference in altitude is also considerable; the lowest spring taken into the pipes for supply being over 900 feet above O. D., and the raised top-water-level of the compensation reservoir, situated upon the main stream of the Wyre, being 356·30 feet above O. D.

This arises from the circumstance that upon the area from which the springs are utilized there does not exist any favourable site for the construction of an impounding reservoir, while at the spot upon which the original reservoir was constructed in 1851 the ground is exceptionally well adapted for the purpose. Two drawbacks may, however, be pointed out: one is that between the points of abstraction of the water for the town supply and the Abbeystead reservoir there is a stretch of river with its tributaries uncompensated for, as being above the stored water, and therefore liable to further claim on the part of the owner. The second is that by coming so low down on the main stream, the drainage area is very largely increased, and consequently the floods to be dealt with in the construction of the reservoir are more difficult to manage. Thus the natural drainage area utilized for supply to the town is only 2,700 acres, while the watershed above the Abbeystead reservoir exceeds 12,000 acres, the former of course being a part of the latter.

The elevation of the ridge of this watershed at its western and eastern extremities is about 1,550 feet, and it rises near the middle of its length, above Wardstones, to 1,840 feet above O. D. The average elevation of what may be called the "supply" district is about 1,450 feet, and the average annual rainfall upon that area is estimated at 54 inches; upon the whole watershed area above Abbeystead reservoir it is probably a few inches less.

The least quantity of water which it is believed has flowed from these 12,000 acres since the works were established in 1852 is about 6,000,000 gallons in twenty-four hours. In 1858, and again in 1869, this minimum was reached, in the latter year after a drought of thirteen weeks. This is equal to 0·926 of a cubic foot per second per 1,000 acres.

The highest flood for many years occurred after the new works of 1876 were completed, and at its maximum the water went over the bywash, which has a lip 167 feet in length, 34 inches deep, to which must probably be added an equivalent of 2 inches more for water passing through a partially opened outlet pipe. At the time of highest discharge the quantity passing would probably amount

to 1,620,000,000 gallons per day, equal to 250 cubic feet per second per 1,000 acres.

Of the 12,000 acres about 8,000 are open mountain pasture and grouse ground, and the remaining 4,000 are enclosed and cultivated lands, but with a very small proportion of arable. High up on the Fells there are considerable patches of peat, and in wet weather the main streams are much stained, but this does not affect the colour of the water supplied to the town, because it is taken for the most part direct from springs.

GEOLOGY.

The range of Wyresdale Fells consists of mill-stone-grit interbedded with impervious shales. The general dip of the country, taken from the underlying limestone in the trough of Bolland, is to the north, and about 12 miles north of this ridge the coal-measures come in above the millstone-grit. Here and there local undulations over limited areas reverse the dip, and undoubtedly increase materially the underground area contributing to the discharge of the springs on the *south* side of the hill. The Author had long been of opinion that this must be the case, judging from the high dry-weather yield of the district, and the fact was conclusively proved by the evidence of Mr. Tiddiman, F.G.S., in a recent arbitration. Mr. Tiddiman had previously surveyed this country as a member of the staff of the Geological Survey; but he was requested last year to make a special examination with reference to this point, and to plot three lines of section from north to south across the Fells, one line nearly through Grizedale spring on the west, the second through Wardstones, and the third near the head of Tarnbrook Wyre on the east (Plate 8). It will be observed that the impervious shale bed, underlying the great mass of millstone-grit which forms the summit of the ridge, has the top of its northern outcrop at a higher level than its southern, and that therefore water percolating downwards through the grit on the north side of the *surface* watershed line, and stopped by this shale, will have a tendency to flow southwards and escape by the Grizedale or other springs. This is shown very clearly on Section A, and would have been more marked if the section had happened to be taken a little more to the east. On the actual line of section the difference in level of the northern and southern outcrops is about 40 feet. Of course this circumstance does not affect materially the amount of flood waters running off the surface, but it undoubtedly maintains and increases the dry-weather yield of the

springs. The underground drainage area, the northern boundary of which is shown by a round-dotted line, is, according to Mr. Tiddiman's observations, 640 acres in excess of the surface watershed area.

NEW WORKS.

The works contemplated under the Act of 1876 were intended to suffice for the supply to Lancaster of 1,500,000 gallons per day. The minimum discharge of the springs appropriated under the Acts of 1851 and 1864 (as ascertained by gaugings in very dry years) is about 630,000 gallons in twenty-four hours. Gaugings were made in 1875 and 1876 of the new springs intended to be added, and simultaneously of the discharge of all the old sources, and the former were reduced to a minimum to correspond with the 630,000 by proportion. By this method it has been judged that, in a year of excessive drought, the total yield of the old and new springs, in addition to the dry-weather flow of Tarnbrook Wyre at the point M, 1,430 feet above O. D., will be 1,100,000 gallons per day. In such a year there would therefore be a daily deficiency of 400,000 gallons. To make up this deficiency it is intended to construct a reservoir capable of holding 50,000,000 gallons in a small valley called Damas Gill, having its top water at an elevation of 583 feet above O. D. (Plate 8). This reservoir is to be filled with the surplus water of the springs authorised to be taken, and not with the water running off its natural gathering ground. Its actual construction will be postponed as long as possible.

Owing to various circumstances which prevailed at the time the Bill of 1876 was being prepared, the arrangements made with regard to the appropriation of a gathering ground area and the compensation water were a little exceptional. The principal of these circumstances was that the Corporation of Liverpool had at that time under consideration a scheme for obtaining water from this and the neighbouring district of Bleasdale, suggested by Mr. Joseph Jackson, and supported by Mr. Hawksley, Past-President Inst. C.E. This scheme included a catch-water channel or conduit along the southern face of the Wyresdale Fells to intercept all the water flowing from them above the level of about 800 feet; but the channel was likely to interfere prejudicially with the springs from which Lancaster was then drawing, and desired to increase, its supply, and therefore Parliament was asked to grant protection against such interference. This was done by a clause in the Act of 1876, which prevents any

person or public body making works for supply of water to any place on any part of the area of 2,700 acres. By this means the integrity of the springs is assured, but the Corporation of Lancaster do not acquire the full right to all the water running off this area. The quantity is limited to 2,000,000 gallons in twenty-four hours, and it is on this restricted quantity that the amount of compensation water is adjusted. The proposal made in Committee by the promoters of the Bill through the Author was that the compensation reservoir at Abbeystead should be so increased in capacity as to contain one hundred and sixty times 1,000,000 gallons, that is, half the daily quantity authorised to be taken to the town for supply. By agreement with the opposing millowners, and in consideration of the Corporation being relieved from a prior obligation to clean out the reservoir, this was ultimately increased to 185,000,000 gallons.

The reserved area of 2,700 acres would, if sufficient reservoir capacity were provided to utilize the whole of the rainfall, produce over 7,000,000 gallons per day. This quantity is much in excess of the requirements of Lancaster, and therefore there was no necessity to incur the cost of obtaining the whole of it; besides, the water, if stored, would have been of a brown, peaty character, essentially different from that heretofore supplied to the town. These considerations led to the obtaining of the special and unusual powers over the area of 2,700 acres, coupled with the limitation of the quantity of water to be abstracted to 2,000,000 gallons per day.

There can be no doubt that in 1851 and 1864 the finest springs upon these Fells were taken. These in the aggregate have yielded, in all but periods of drought, far more than the 700,000 gallons per day authorised to be taken under the Acts of those two years. The Act of 1876 was required, therefore, not only to sanction the appropriation of additional springs at a lower level and Tarnbrook Wyre at the point M (Plate 8), but also the taking for supply of the surplus water of the old springs. In determining which of the many springs to turn into the pipes the requirements of the district for pastoral and agricultural purposes had to be considered, and in this respect the landowners' and landholders' rights were amply protected, not only by the Waterworks Clauses Act, section 15, but by the 19th section of the special Act of 1876.

A novel claim was, however, set up by the owner of the Fells, which at the time excited considerable interest in the north of England, especially among public bodies obtaining their water supplies from similar districts.

In the course of the Author's investigations, preparatory to his report of 1875, he became aware that the discharging power of the original 8-inch main, laid about 1852, was seriously diminished. This had, in fact, been known for several years, so that in 1866, partly on this account and partly to insure the non-interruption of the supply, an additional 10-inch main had been laid from the service reservoir to about 600 yards east of the river Conder. In 1866 the discharge of the 8-inch pipe was found to be only 450,000 gallons per day, whereas theoretically it should have been nearly 650,000. After the 10-inch pipe was laid the head was increased by putting out of use an intermediate break-pressure chamber near the Dog and Partridge P. H. With this additional head, and the help of the 10-inch at its lower end, the 8-inch pipe should have been able to deliver about 1,900,000 gallons per day, but in 1871 it would only pass about 1,000,000, and in 1875 only 850,000. The Author therefore advised that the 10-inch pipe should be extended up to the point where the new low-level line from the Fells would join the old pipes after coming round by the Damas Gill valley, and that the old 8-inch pipe should be scraped. In order to provide for similarly treating the new 10-inch at some future time door-pipes were inserted in it at intervals as it was laid.

The scraping was executed in August, 1878, with an instrument made by Mr. Kennedy of Kilmarnock, on the principle suggested by the late Mr. Appold. The following is an extract from a report made to the Corporation on the subject by Mr. William Roper, the chairman of the Water Committee:—"Owing to the difficulty in obtaining the usual quantity of water, and the continuous decrease in the discharge of the main attributed by Mr. Mansergh, our engineer (in his report of 1875), to the reduction of the sectional area of the main caused by incrustation, and, acting upon his advice, the authority authorised the purchase of apparatus suitable for cleaning the pipes. The first trial was made on August 1st, from Brow Top basin to the river Conder (where there are duplicate mains), a distance of about 1,760 yards. A door-pipe was placed in the main, a short distance below the Brow Top basin, in order to obtain a head of water equal to 20 feet to commence with. Another door-pipe was placed in the main near Conder Bridge, the difference in level between these points being about 360 feet. Upon turning on the water at Brow Top the scraper started with a low rumbling noise, travelling at the rate of about 6 miles per hour for a distance of nearly 1,300 yards, when it was stopped by the lower portion of a valve which projected into the main. After the removal of this obstruction the scraper continued its course at about the same rate as before, propelling in front of it, and sending out of the lower

door-pipe, huge quantities of scale and peaty substance. The result being so successful the Committee were encouraged to clean another length, namely, the single line of pipes (also laid in 1854) between the High Cross Moor reservoir and the Appletree basin, the distance being about 1,500 yards, and the difference in level 220 feet. Two door-pipes were fixed in this length, one about 50 yards below the High Cross Moor reservoir to obtain the necessary working head at starting, the other a few yards from the Appletree basin. In preparing the door-pipe at Appletree basin a portion of the main pipe was removed, the inside diameter of which was found to be reduced from 8 inches to $6\frac{1}{2}$ inches by incrustation and adhesion of peaty and other substances to the inside of the pipe. On the 23rd of August, 1878, this length was cleaned by sending the scraper twice through the pipe. The result was perfectly successful, and the discharge of the pipe restored to its normal quantity. By an experiment tried that night it was found that the increased delivery of the main amounted to 56·51 per cent." Mr. Roper then goes into considerable detail as to the cost, and ultimately arrives at the conclusion that if the 8-inch main is scraped once in three years, and allowing 10 per cent. per annum for interest and wear and tear on the value of the scraper, the annual expense will be equivalent to £1 16s. 6d. per mile. The material removed from the pipes by the scraper was examined by Dr. Harker, the medical officer, who made the following report upon it: "The material is of a light spongy brown appearance, resembling gingerbread in colour and consistency. As removed by the scraper from the water pipes the larger flakes measure $\frac{3}{4}$ of an inch in thickness. A small portion diffused in water, when examined by the microscope, is seen to consist of fine amorphous particles of a brown colour.

CHEMICAL EXAMINATION.

Water	64
Organic matter and water of composition, consisting chiefly of brown insoluble vegetable matter, common to all soils	23
Mineral matter after incineration	13
	<hr/>
	100
	<hr/>

Of this mineral matter there was :

Iron protoxide	7
Silica in minute crystals (silver sand)	2
Alumina	2
Lime and other soil matters and loss	2
	<hr/>
Total	13
	<hr/>
	s 2

N.B.—The mean result of two examinations is given, as by evaporation the substance changes in density from day to day.

Observations.—The scrapings are therefore fine soil matters, deposited under high water pressure, and iron rust from the pipes.”

The results of these scraping operations have been exceedingly satisfactory, and this short record of them may be useful in other cases.

Before the extensions authorised by the Act of 1876 were carried out, the works supplying water, exclusive of distributing pipes, valves, hydrants, &c., in the town, were the following :

A covered service reservoir, containing 580,000 gallons, situated on Lancaster Moor near the Workhouse (Plate 8), and having its top water at 245 feet above O. D., or about 160 feet above the average level of the town. An 8-inch and a 10-inch main from the service reservoir laid along the public road to a point about 600 yards east of the river Conder, where they were connected. An 8-inch main in continuation of the above to a break-pressure tank near the Dog and Partridge public-house, 473 feet above O. D., and forward through a similar tank at Appletree, 739 feet above O. D., to a covered reservoir on High Cross Moor, having a capacity of 450,000 gallons, and its top water-level at 953 above O. D.

Adjoining the reservoir a gauge-house and apparatus to measure the 700,000 gallons allowed to be taken by the Act of 1864.

Above the reservoir (where the iron pipes terminate) a line of 12-inch stoneware pipes, laid about the year 1852, as far as Grizedale brook, and another line of 15-inch, 12-inch, 9-inch, and 6-inch stoneware pipes, laid about the year 1865 up as far as Thrush Clough at L, with smaller branches to springs. The pipes laid in 1852 have puddle joints, and those laid in 1865 have cement joints.

The new works executed under the Act of 1876, in connection with the supply of water to the town, are the following :—

1. A 10-inch cast-iron main from a point about 600 yards east of the river Conder to the Brow Top basin.

2. The Brow Top basin, which is a small break-pressure tank situated alongside the public road at the point where the pipes bringing the low-level supply from the Fells join the old 8-inch main. The top water-level is 553 above O. D.

Adjoining this basin is a chamber in which the pipe connections have been so contrived that the six valve-spindles are arranged symmetrically in two sets in a compact and handy form (Plate 9). It will be noticed that the new 10-inch main has been made good to the old 8-inch main above, as well as to the basin.

3. From Brow Top basin the new and low-level line consists of 18-inch stoneware pipes contouring the hill side with a gradient of 1 in 700 as far as the site of the intended Damas Gill reservoir. This pipe will ultimately take the water from near the bottom of that reservoir. The pipe intended to bring the water into the reservoir is of 12-inch stoneware, and the two pipes are now connected across the valley by a 12-inch iron pipe. Above the 12-inch there is another length of 18-inch stoneware pipes laid on a gradient of 1 in 588 in deep cutting up to the new gauge basin.

4. In accordance with the provisions of the Act of 1876, a means of gauging the water sent to the town had to be provided for the satisfaction of the parties interested in its diversion, and by a subsequent Act of 1880 it was made quite clear that part of the 2,000,000 gallons per day might be passed through the old iron main of 1852, or the whole quantity might be conveyed through the new pipes, by way of Damas Gill. The new gauge-house is situated on Abbeystead Fell, near a small stream called Worm Syke (Plate 8).

The Author believes the form of gauge is novel, and he therefore gives the following description of the arrangements (Plate 9). The house is about 18 feet by 14 feet inside, and is divided below the floor into five chambers, A, B, C, D, E. Into A the new low-level pipe line, 15 inches in diameter, and a 9-inch pipe bringing the surplus water from the old and upper line, discharge, and in the ordinary course of working the water passes into B, through the gauge into the measuring chamber C, and then by the overflow into E, and so into the main 18-inch pipe away to the town. If it is desired not to pass the water through the gauge, the 12-inch valve in D is opened, and gives direct access to the 18-inch pipe through E.

The measuring chamber C is 8 feet square, and has an available depth for measuring of 5 feet, its content therefore being about 2,000 gallons. Its purpose is, first, to give accurate means of adjusting the gauge; and secondly, to provide the millowners a direct mode of measuring the water passing to the town during any given time.

The gauge apparatus consists of a cast-iron pipe 2 feet wide, and about 8 inches deep, opening freely at one end into the measuring chamber C. At the opposite end it is turned up at right angles in the shape of a short cylinder having an internal diameter of 24 inches, and upon it is bolted vertically another cast-iron cylinder 10 inches deep, and $24\frac{1}{2}$ inches in diameter. This is lined with a cylinder of gun metal 24 inches in diameter. Across the bottom

is fixed a gun-metal guide for the gauge spindle. Working accurately in the fixed gun-metal cylinder is another of smaller diameter, 8 inches deep, attached to a centre spindle, and free to move up and down vertically, and immediately above this is a similar cylinder attached to the same spindle, and movable upon it by means of a screwed thread. To this upper cylinder is secured a galvanised iron float 4 feet 8 inches in external diameter. By means of the screwed spindle the upper cylinder can be drawn away from the lower one, or brought nearer to it, so as to leave an aperture of any desired opening. The water is measured by passing through this aperture. As now set, it is delivering 1,300,000 gallons in twenty-four hours, whilst the 700,000 gallons authorised by the Act of 1864 are being delivered through the gauge basin on the upper pipes; but it is easily adjustable for the 2,000,000 gallons per day, or for any other quantity.

To adjust the gauge it is only necessary to draw the lips of the two cylinders apart to the extent approximately ascertained by calculation, and then by means of time trials with the measuring chamber to fix and secure the exact opening by the screwed spindle. This adjustment being made, the float and connecting spindle keep a constant head upon the aperture, and consequently a constant discharge.

The measuring chamber C is connected to a chamber F outside, by a 12-inch cast-iron pipe, provided with a sluice-valve G. The end of this pipe in the measuring chamber is cast with a face bevelled at an angle of 45° , and is closed by a tight-fitting flap-valve H, which can be readily lifted or lowered by a chain brought up to the house floor. Prior to measuring, the chamber is emptied by opening the flap and sluice-valve, and the water gets away by a wash-out pipe into Worm Syke.

A pine rod secured to a float K, properly guided, is brought up through the floor, and has secured upon it a brass engraved plate having on one edge a quantity scale, and on the other a time scale for the 1,300,000 gallons in twenty-four hours. By means of these scales the quantity of water passing through the gauge in twenty-four hours can be ascertained in a few minutes, the operation being as follows:—

Having emptied the chamber C, the flap H is let down and the water begins to rise in the measuring chamber, and with it the float and rod K, and in a few seconds the zero on the brass scale comes opposite a fixed pointer about 4 feet above the floor. At this moment the time is noted, and at the expiration of one minute the figures on the left edge, opposite the pointer, indicate the

number of gallons of water per twenty-four hours passing through the gauge.

In chamber B there is a fixed overflow 8 feet long, by which the surplus water coming into the gauge-house is conveyed through F into Worm Syke, and so on into the river Wyre.

5. Beyond this gauge-basin the sizes of the pipes diminish through 15, 12 and 9, to 6 inches in diameter, according to the work they have to do, and there are smaller branches to the springs.

6. A 9-inch pipe connects the old and new line at this gauge-basin.

7. Where the 6-inch pipe comes up to Tarnbrook Wyre at M (Plate 11), a masonry weir about 3 feet high has been built across the river, so as to turn the water into the pipes when required. Upon the new line and its branches from Brow Top basin to Tarnbrook Wyre, about 16,730 yards of pipes have been laid, and there are upon it 25 manholes, sixteen ventilators, and twenty-five occasional inspection shafts. All the pipes have "Stanford's patent points." Grizedale brook is crossed by an iron pipe laid as an inverted Siphon, and the two Within Sykes, Wood Syke and Tarnsyke Clough, are each bridged by one stone arch.

The foregoing is a description of the works of supply as they now stand. In the course of a few years the Damas Gill reservoir will have to be made; but there is a strong feeling in the town in favour of the fresh spring water *unstored*, and therefore its construction will no doubt be delayed as long as possible.

The Author will now describe the works required for the provision of compensation water by means of the Abbeystead reservoir.

ABBEYSTEAD DAM (Plate 10).

In order to make intelligible the description of the new dam, it will be necessary also to describe shortly the original construction of 1851, and the additions subsequently made up to 1864-5.

The first weir erected, from Mr. Rawlinson's design, consisted of a vertical rubble masonry wall built on a curve in plan across the river, and abutting at each end against the solid rock sides of the valley. The length of this wall was about 100 feet, its height 30 feet, its thickness 6 feet, and its down-stream face was struck with a radius of about 80 feet. Two arched openings, each 6 feet wide, were left in it for the passage of the river during construction. On the reservoir side this wall was backed up with dry stone packing, covered with masonry pitching, on a slope of 1 to 1.

The down-stream side was of similar construction, but the pitching was of a superior character, and was formed to an ogee section running at the bottom into an apron of similar material, and about 40 feet in length, having at its foot a low vertical wall, in which were the discharging ends of two 3-feet iron pipes laid under the apron, and main wall to the inner face of the dam. The discharge valves were fixed on the inner slope, and worked with racks and pinions.

All the water which did not pass through the pipes ran over the top of the dam, and fell on to the apron and so on into the river. At that time the total height from ordinary water-level in the river to the top water in the reservoir was about 22 feet.

This dam did not turn out to be quite tight, and a few years after its completion it was strengthened by having a wall of concrete 3 feet thick, and another of rubble 3 feet 6 inches thick built against its back. In 1864 and 1865 the dam was raised 8 feet 6 inches by building a wall of concrete, another of rubble, and another of puddle, respectively 5 feet 3 inches, 4 feet 6 inches, and 5 feet 6 inches thick behind the old work. The puddle wall was backed up with dry rubble, finished with hammer-dressed pitching to a slope of something less than 1 to 1. Wing walls were carried back beyond the foot of this slope containing the two outlet pipes, and vertical discharge-valves were fixed in a recess at the bottom and worked with vertical spindles by gearing on the top of the walls. The crest of the raised dam was finished with tooled pitching 15 to 18 inches thick; a second and lower apron was put in below the outlet of the discharge-pipes, and a fish-pass was constructed on the south side of the river.

All this work was carried out under the superintendence of the then town surveyor, Mr. Henry Harrison, without any special provision being made for passing floods. The season was exceptionally favourable, and the whole work was completed without an accident.

In 1876 the Author was called upon to increase the capacity of this reservoir from 76,500,000 to 185,000,000 gallons. To do this it was found by careful levelling and contouring that the top-water would have to be raised exactly 10 feet. At that time the dam was causing some little uneasiness on account of the shaky condition of the upper apron. How this apron had withstood for so many years the impact of the great body of water which frequently thundered down upon it is astonishing. That the water passing over the dam has frequently been 4 feet 6 inches deep is well authenticated, and it is believed that at times it has, for short

periods, been 5 feet deep. At such times the water took almost a clear leap over the original crest of 1852, coming fairly down upon the apron, rebounding upward to a height of 15 or 20 feet, and then leaping forward again into the river.

After careful examination, which resulted in showing that a little water was leaking through the work, and that the apron was in such a condition that any flood might blow it up, it was determined to erect a new wall immediately in front of the original vertical wall of 1852. It was not considered safe to obtain the additional height required by building upon the old composite structure of rubble, concrete, and puddle, nor was it deemed prudent to allow the water to fall over the weir itself when raised, as it had done in 1852, and continued to do after the heightening in 1864, and moreover it was thought desirable to provide fully for the passage of floods during construction. The new design included, therefore, the construction of an overflow and by-wash to convey flood waters down the south side of the valley into the river below.

To place the back of the new wall against the front of the old wall of 1852, the curved pitching and its substructure of dry rubble, and a part of the apron, had to be removed. In plan the curve of the back of the main wall is carried round on the south side to form the inner face of the north wall of the by-wash. On the north the main wall is turned back at an angle of about 95° into the hill side in order to save work. If the wall had been continued on the same curve, or even on a straight line tangential to the curve, it would have run into lower ground, and would consequently have been much higher. As built, this part of the wall is outside the steep valley, is comparatively low, and is a stable structure against the pressure it has to bear. The curved part of the wall, which may be considered as a horizontal arch, has an abutment at each end against the solid rock forming the sides of the valley. The lip of the overflow is struck with the same radius as the back of the main wall, namely, 80 feet, and it is built on this curve for 140 feet out of its whole length of 167 feet, 27 feet at the south end being straight. The centre line of the by-wash runs into the river at an angle of about 36° .

There is a total fall of about 40 feet from the crest of the overflow to the ordinary water-level in the river at the foot of the by-wash, and this fall is divided as follows:—13 feet are used in the reverse curve at the top in a length of 29 feet; next there is a straight slope of 1 in 6 for 90 feet in length, with a fall of 15 feet to the foot of the pitching, at which point the channel is 36 feet wide. There is then a length of about 60 feet open on the river

side, finished with concrete, having a fall of a foot, and terminating with a nearly vertical drop of 10 or 12 feet.

On the north side of the river there is a fish-pass built of masonry, 3 feet 6 inches wide, with chambers divided by 6-inch landings, 4 feet 6 inches in length. This pass is about 220 feet long, and has a rise of 1 in $5\frac{1}{2}$.

The original 3-foot discharge pipes are retained just as they were left in 1864, only that the new wall is built round and above them. Towers have been carried up over the old valves inside the reservoir and their spindles lengthened, and a sluice-valve has been fixed in each pipe on the low side of the main wall. The towers are reached by light wrought-iron lattice girder bridges from the parapet of the main wall.

From the north discharge pipe a 15-inch branch is taken off above the sluice-valve for the delivery of the compensation water in accordance with the Act of Parliament. The quantity to be discharged is 3,000 gallons per minute for fourteen hours five days a week, and ten hours on Saturday. The 15-inch branch is made good to a vertical 3-foot cast-iron cylinder, with a closed top, having on its down-stream side an opening commanded by a valve, through which the water is delivered into a circular pond or basin, built on part of the site of the old apron.

The working gear of the valve is fixed upon the top of the cylinder, and a brass engraved plate and pointer indicate how much the valve has to be opened to pass the requisite quantity under the varying head of water in the reservoir. The outlet of the basin is furnished with a notch-plate, by which the quantity discharged may approximately be checked.

MODE OF CONSTRUCTION.

The works thus generally described were carried out in three sections—

First. On the north side of the river the part of the main wall from the extreme north end to the top of the steep valley slope, about 120 feet in length, the concrete being temporarily finished to a batter of about 4 inches to 1 foot; also the fish-pass.

Secondly. On the south side the overflow, by-wash, and rough channel, to the river, and a short piece of the main wall as on the other side.

These two sections were carried on simultaneously, the water passing meanwhile as usual through the two discharge pipes, and in flood over the top of the old weir. When they were completed

a coffer-dam was erected on the old work formed of two rows of 3-inch timber sheeting, and main piles enclosing puddle carried vertically upwards in continuation of the old puddle-wall, the whole strongly strutted up from the wing walls and body of the old work with timber.


This dam was carried forward at each end, and made good to the new wall. Its height was 3 feet above overflow level, and its effect, when finished, was to turn the flood waters down the new by-wash. It was expected by this means, that is under cover of the cofferdam, that the main wall might have been completed without further interference by the water. The old pitching and rubble backing of 1851 were removed with a great part of the old apron, and the rock and shale were excavated to make room for the wall foundation.

Everything was, in fact, got ready by the end of June, 1879, for commencing the putting in of the concrete bottom, when a succession of floods came which materially interfered with the operations, and necessitated a modification of the plan of procedure. On three days following each other the water rose at times so as to pass over the top of the overflow from 18 to 26 inches in depth, and at the same time a violent storm of wind blew up the valley. On the 2nd of July the part of the dam driven in the ground between the old work and the new wall on the south side began to show signs of weakness, and finally the water got behind and under it, and carried it away for a length of about 30 feet, leaving the remainder standing. One side of this opening was the old wing wall and the coffer-dam above it, and the other the battered face of the new concrete wall. On the site of the dam a depth of 8 or 9 feet of earth overlay the rock down to which the timbers were driven. This was all carried away, and in addition several beds of live rock, 18 inches to 2 feet in thickness. Further into the reservoir the earth and rock were bared to about 16 feet below overflow level, so that betwixt 17 and 18 feet of water over an average area of about 35 acres were let out (27,000,000 cubic feet), in addition to the flow of the river, in the course of five or six hours. Fortunately this discharge (limited by the narrowness of the gap) was insufficient to overfill the bed of the river below, and no damage was done along its course, nor did the permanent works suffer. The sharp arris of the concrete at the back of the new wall, which formed one side of the channel was only somewhat rounded and polished, but not a stone was disturbed.

After this experience it was considered better to utilise the opening than to restore the coffer-dam. The rest of the dam was

therefore taken down, and the materials were used in the construction of a timber shoot, 20 feet wide and 10 feet deep at the upper end, having its floor laid with a fall of 1 in 6. At its inlet a bell-mouthed opening was formed for the easy inflow of the water, and the mouth of the shoot was made good to a timber sill bolted down to the rock and caulked with concrete. The lower end was carried sufficiently forward to discharge the water into the river well in front of the face wall of the apron. It had been intended to found the new wall in a bed of shale 4 feet below the footings of the original rubble wall of 1852. This flood, however, scoured out parts of the bottom 7 or 8 feet deeper, and then filled the hole up with *débris*. When this was cleared out, it was found necessary to excavate in order to level the foundation, a length of 43 feet to a depth of 17 feet below the bottom of the old wall. The new wall has therefore, in the centre of the valley, a total height of 64 feet. It is formed of concrete gauged 1 part of Portland cement to 4 parts of stone broken in a machine, the whole of the "breakings" being used without any special admixture of sand, as it was found that these, when the cement was added, formed a solid mass free from all interstices and vacuities. The stone used in making the concrete was obtained on the site of the works or from a quarry within the distance of half a mile, from which a tramway was laid by the contractor. All soft and dirty stones were rejected. The cement and broken stone were passed together through a mixing machine driven by steam, and water was added in what would, by many engineers, be considered excessive quantity. The Author's experience is, however, that it is hopeless to expect to make watertight concrete without plenty of water. Dry concrete cannot be solidified, but will be full of interstitial spaces through which water, even under very low pressure, will pass with facility.

In this work, after being mixed as described, the concrete was either sent down by shoots or tipped, not more than 6 feet, from stages, and was then trimmed in regular layers of about 6 inches, and "put down" with beaters until it was solid, any excess of water coming to the top being allowed to drain quietly off. It was noticed sometimes that the water so draining off appeared to be taking with it some of the cement, but on examination this was found not to be the case, the material so removed being apparently a little dirt from the stone. The Author is strongly of opinion that failures in making concrete water-tight are far more likely to occur from using too small a quantity than too large a quantity of water.



About 20 feet in height of the base of this wall were put in during the winter months of 1879, but no work was done whenever there was frost in the daytime; and to prevent the concrete being injured in frosty nights the water was allowed to rise, when work was stopped in the evening, and submerge the whole of it.

Before laying fresh concrete on a set surface this was thoroughly scoured with bristle brooms and clean water, and before joining up to the battered ends of the walls previously built on the valley sides the old concrete was picked and well washed and wetted.

The wall from just below the old apron level was faced on the down-stream side with block-in-course masonry carried up with the concrete and set in cement. At its back it was built up against the front of the old rubble wall, and above the top of that wall it was rendered with cement gauged 4 parts of cement to 1 part of sand, well trowelled and "set up" to a fine face.

Of course in building the wall a gap had to be left round the flood water shoot, one side of which was the battered end before described on the south side of the valley. This gap was 25 feet wide at the bottom, and, to allow of toothing back the masonry, 40 feet wide at the top, and it was 34 feet deep. The concrete had been brought up to within about 4 feet of the under side of the shoot, surrounding as it was put in a solid stone pier about 2 feet 6 inches square, which had been erected to carry one side of the shoot-framing. When all was ready the shoot was cut across just in front of the face of the wall, and its outer end, properly supported, was left to receive as much of the water as possible if a flood should occur while filling the gap. It was considered undesirable to carry up the concrete in this opening at any greater speed than the other part of the work had been erected, and therefore progress was necessarily slow. No great damage could have been done even if a flood had occurred; but it was a source of satisfaction that, during the eighteen days occupied in closing this opening, the quantity of water coming down the river was always under control of the storage capacity of the reservoir and the discharging power of the outlet pipes. From this description it will be seen that there are three straight joints in this work, but there is no sign of the least unequal settlement or other movement.


The gap in the wall being closed, the footway was formed, the handrailing and parapet were erected, and the two bridges put in their places, the water being now free to rise and go down the by-wash.

An examination of the general plan of the works and the longitudinal section of the by-wash (Plate 10) will show that a point requiring serious consideration was as to what would happen where this by-channel joins the river. In plan it comes in at an angle of 36° , which would apparently have a tendency to drive the water violently against the north bank. The length of the overflow lip is 167 feet, and the opening at the bottom of the 1 in 6 channel is 36 feet, and the pitching presents a smooth surface for the water to run over without either steps or breaks. The velocity of the water at the bottom of the channel is under these circumstances very great. At the foot of the pitched channel the invert is struck with such a radius that the versed sine is 1.75 foot. Between this point and the river the rock was roughly quarried to the natural beds, but so as to allow a minimum depth of about 2 feet from the intended finished surface of the channel. The joints were then all run in with cement and fine gravel, and a bed of cement concrete was laid over the rough rock, the surface working out from the curve at the foot of the by-wash to a level line at the top of a face wall adjoining the river. This wall is built of cement concrete faced with coursed masonry. Its average height is about 16 feet, and it is founded some 8 or 9 feet below the rock bed of the river.

In floods the water comes down the by-wash entirely unchecked, and, having acquired a high velocity before reaching the bottom, leaps over into a deep pool, by which its forward motion is arrested, and it appears to have no tendency to work into the north bank. In front of the north pier of the footpath bridge a concrete wall faced with masonry has been built, and carried round with a curve back into the solid rock side of the valley, so that no soft material is exposed for the water to work upon. After rushing and tumbling violently into the river the water has a tendency to work back and scour the bed towards the wall, but this has been carried so far down as to preclude the chance of any injury being done. After whirling and eddying in the pool the water takes its natural course down the river.

A footpath bridge of wrought iron of 60 feet span, with small side openings, has been erected over the river a short distance below the dam, to replace a single plank span which formerly existed.

The top water area of the enlarged reservoir is about 50 acres in extent, and it is fenced round in great part by a dry stone wall, with jim-crow coping in mortar, and in the remainder (on ground having a tendency to slip) with Morton's bar-iron fencing.



The cost of the supply and compensation works from the commencement to the present time has been as follows :—

All the works of 1876, from Brow Top to Tarnbrook, were carried out by Mr. Henry Potter at a cost of £9,947; the enlargement of the Abbeystead reservoir by Mr. Joseph E. Hannah, Assoc. M. Inst. C.E., came to £21,528. Both of these gentlemen deserve great credit for the satisfactory way in which they completed their contracts.

The stoneware pipes were supplied by Messrs. Doulton from their St. Helen's manufactory.

Mr. A. C. Watson acted under the Author as Resident Engineer.

ARBITRATION CASE.

As has been before stated, a claim was set up in this case by a landowner of a very startling character, which the Corporation, after making certain proposals in hope of coming to a settlement, felt compelled to resist, and the matter was finally determined between the parties by arbitration.

The facts were shortly as follow : For the purpose of obtaining the water of Tarnbrook Wyre at 1,423 above O. D., and of the surplus yield of the old springs, it was necessary to lay upon the claimant's land 8,750 yards of pipes, ranging from 18 inches to 3 inches in diameter, 580 yards being in enclosed land, and 8,170 yards on the open fell. Of these 7,192 yards were called (in the "notices to treat") "main pipes," and 1,558 yards "branches," and on the former the Corporation desired to acquire an easement over 7 feet in width, and on the latter of 3 feet in width. This land was not to be fenced in nor treated in any other way so as to give rise to severance or interfere with its occupation, and the pipes were buried under ground excepting for a very short length, where in four places they were carried over streams on arches. The area of all the land over which the easement was sought (this being to all intents and purposes just as useful for occupation after the pipes were laid as before) was 3 acres 3 roods 7 perches, and the total actual appropriation of land for manholes, ventilators, bridges, &c., on the whole length of pipes was 167 square yards.

By the Acts of 1851 and 1864 the Corporation had power to take 700,000 gallons of water per day, and by the Act of 1876 they were authorised to increase this taking to 2,000,000 gallons. Of the surplus of 1,300,000 about 1,100,000 gallons were expected to be obtained from the claimant's land, the rest coming from springs on another property. Of course the claimant's right in respect of

this water went to the extent of its fair user in passing through his property.

In addition to these legitimate grounds of claim, namely, for the pipe easements, the actual occupation of land, and the abstraction of the water, there was a small injury to the fishery in the Tarnbrook Wyre above the compensation reservoir, by reason of the diminution in the quantity of water running in it.

The claimant stated that he had originally based his claim of £30,000 on the assumption that the water to be taken, rising as it did on his land and running through it, was his absolute property, and that he had a right to sell it. He had, therefore, valued it at $\frac{1}{2}$ d. per 1,000 gallons, and multiplying the quantity to be taken (1,300,000 gallons per day) by that figure, and capitalising at twenty-five years' purchase (this was a mistake, and should have been thirty), he arrived at the £30,000.

After taking further professional advice, however, he learned that this was not a tenable position, and therefore the case was put before the arbitrator mainly as one in which a valuable sporting estate was going to be greatly injured, if not entirely ruined, by the abstraction of water. The amount of the claim remained unaltered.

The first witness's evidence was of the simplest character, and to something like the following effect: The claimant's grouse moor is worth £1,200 a year. By the making of the works and abstraction of the water this will be depreciated to the extent of £900 a year. £900 by thirty-three years' purchase = £29,700.

Gamekeepers and others were called from Scotland and elsewhere to prove the value of grouse moors in general, and the claimant and his own keeper spoke to the value of this moor in particular.

Then a north country land agent and valuer of large experience proved that the claimant was entitled to £23,274. His valuation was based on the assumption that the 8,000 acres of moorland belonging to the claimant were worth £10 an acre, and by the taking away of the water would be depreciated one-third; and after some manipulation with the 2 per cent. table the annual loss was capitalised at thirty-five years' purchase, producing £18,550. Similarly, 350 acres of enclosed land were asserted to be injured to the extent of £3,062, making, with the £18,550, £21,612. The pipe line easements were valued at £1,662, which added to the previous figures made the total above named of £23,274.

A second valuer called immediately afterwards gave the same figures, but two others on the same side, who did not give

their evidence until an adjournment of a month had taken place, brought the value of the claimant's injury down to £16,035.

All these valuations, gradually becoming smaller as the process of cross-examination showed their fallacy, were based on the assumption that practically the whole of the water was to be taken away, the effect of which would be to destroy the moor for grouse culture, especially the parts on which the birds were in the habit of breeding.

Engineers were then called to prove how little water was left on the fells in October, 1880, after the springs had been turned into the new pipes, and how much less there would be in extreme drought.

On the part of the Corporation this part of the case was met in the following manner. According to the claimant's witnesses the best breeding-ground was a triangular piece lying between Tarnsyke Clough (on the west), the new pipe on the north, and Tarnbrook Wyre on the south (Plate 11). If the water were taken from this piece the breeding-ground would be destroyed. It had, therefore, to be proved that such would not be the case. Before the middle of October, 1880, all the springs intended to be appropriated had been turned into the pipes, but Tarnbrook Wyre was still running undiminished down its usual course. On the 19th of October (during an adjournment) all the streams left untouched on the fells, and still running down their usual channels, were gauged where they crossed the new pipe. On the 20th the same streams and others which issued from springs below the new pipe were gauged just above their junctions with Tarnbrook Wyre. The result was that between Wood Syke, the western boundary of the claimant's (affected) property, and the point M. on Tarnbrook Wyre, twenty-two streams, small and large, were found to be running either over the new pipe or under it where it was carried on arches, and the aggregate quantity of water was something over 220,000 gallons per day.

The daily quantity of water discharged by these streams into Tarnbrook Wyre was 470,000 gallons, thus showing that in crossing the breeding-ground the streams had grown to the extent of 250,000 gallons in twenty-four hours. On these days, therefore, it was evident that sufficient water was left for all agricultural and pastoral purposes, and therefore of necessity also for the grouse.

But this was not sufficient, for it might have been stated that on the days of gauging, either by reason of recent rains or of a

previous wet season, the quantity of water running off the ground must necessarily have been above the average, or at all events above a dry weather discharge.

That this was not the case was shown by an investigation of the rainfall. First, it was not questioned that the streams were not swollen by recent showers, for the weather had been dry for some time, and it was admitted that the water running on the 19th and 20th of October might fairly be considered as the produce of springs more or less deep seated.

Then with regard to the previous season's rains, the records of the two nearest long kept gauges, namely, at Lancaster and Stonyhurst, were made use of. The rainfall of every year, beginning the 1st of October and ending the 30th of the following September, was tabulated from 1862 to 1880. The 30th of September was chosen, because it was the latest date before the time of gauging the streams that a complete year could be obtained. The following is the rainfall at Lancaster :—

Year ending	Inches.	Year ending	Inches.
30th September, 1862 .	45·89	30th September, 1872 .	55·45
„ 1863 .	44·49	„ 1873 .	39·53
„ 1864 .	42·62	„ 1874 .	34·65
„ 1865 .	35·03	„ 1875 .	40·48
„ 1866 .	45·35	„ 1876 .	37·24
„ 1867 .	40·29	„ 1877 .	48·80
„ 1868 .	31·98	„ 1878 .	45·24
„ 1869 .	46·37	„ 1879 .	37·75
„ 1870 .	33·25	„ 1880 .	29·66
„ 1871 .	38·95	Average of nineteen years	40·69

Rainfall of year ending 30th September, 1880, of the average of } 73 per cent.
nineteen years

From this it will be seen that the rainfall of the twelve completed months immediately antecedent to the time of making the stream-gaugings is the lowest that has been recorded during the whole series of nineteen years, namely, 29·66 inches, or only 73

per cent. of the average of the nineteen years, which is 40·69 inches. The next lowest fall was in 1867-8, namely, 31·98 inches, and the largest fall was in 1871-2, namely, 55·45 inches.

The Stonyhurst Table is as follows:—

Year ending	Inches.	Year ending	Inches.
30th September, 1862 .	50·80	30th September, 1872 .	58·62
„ 1863 .	51·87	„ 1873 .	47·16
„ 1864 .	48·73	„ 1874 .	50·25
„ 1865 .	36·95	„ 1875 .	48·56
„ 1866 .	54·15	„ 1876 .	49·11
„ 1867 .	52·66	„ 1877 .	51·25
„ 1868 .	37·94	„ 1878 .	53·94
„ 1869 .	56·09	„ 1879 .	44·67
„ 1870 .	42·64	„ 1880 .	39·73
„ 1871 .	52·96	Average of nineteen years	40·69

Rainfall of year ending 30th September, 1880, of the average of } 81 per cent.
 nineteen years

In this case the rainfall of the last completed twelve months before the date of the stream gaugings is the lowest but one in the nineteen years' series, and is 81 per cent. of the average.

Further it was urged that as a rule, except in hot summers, springs are usually at their lowest in October, and that springs issuing from the base of a thick mass of rock might be expected to have a relatively high or low discharge in that month, in proportion to the quantity of rain which had fallen in the previous winter. The four winter months November, December, January, and February, are those months in which, on account of the small amount of evaporation and the non-activity of vegetation, of the rain which falls the greatest proportion percolates into the ground. That is to say, in a district of this sort, if there is an abnormally small rainfall in the winter months, a low discharge from springs may be expected in the following autumn.

In order to find out the fact with regard to the winter rains, the following Table was prepared, showing the rainfall at Lan-

caster and Stonyhurst in the four months—November, December, January, and February of every year from 1862-3 to 1879-80.

Four Months' Rain ending	Lancaster.	Stony- hurst.	Four Months' Rain ending	Lancaster.	Stony- hurst.
February 1862 .	Inches. 14·11	Inches. 16·13	February 1872 .	Inches. 16·75	Inches. 16·21
„ 1863 .	13·52	15·97	„ 1873 .	15·90	15·88
„ 1864 .	12·72	20·20	„ 1874 .	9·08	12·38
„ 1865 .	14·67	15·10	„ 1875 .	12·86	15·93
„ 1866 .	14·67	16·57	„ 1876 .	13·63	17·59
„ 1867 .	18·88	25·48	„ 1877 .	19·12	19·15
„ 1868 .	10·99	14·92	„ 1878 .	17·59	20·41
„ 1869 .	21·75	25·38	„ 1879 .	8·97	10·07
„ 1870 .	14·93	19·65	„ 1880 .	5·57	9·58
„ 1871 .	10·88	13·97	Average of nine- teen years . . }	14·03	16·87

Rainfall of four percolation months of 1879-80 is of average	} Per Cent.	Per Cent.
of nineteen years		
	40	57

From this it will be seen that at Lancaster the mean rainfall of the four winter months for the nineteen years was 14·03 inches, and that of the four winter months 1879-80 was 5·57 inches, or only 40 per cent. of the mean; and that at Stonyhurst the average was 16·87 inches, and the fall of the winter months in 1879-80 was 9·58 inches, or 57 per cent. of the average.

Moreover, as it had been suggested by some of the claimant's witnesses that it was the rainfall of a comparatively short period (two or three months) anterior to the date of the spring gaugings which affected their discharge, the amount of rain which had fallen in August and September of the nineteen years was tabulated, and at Lancaster the average was found to be 8·66 inches, and at Stonyhurst 9·65 inches, whilst in the August and September of 1880 it was at Lancaster only 6·58, and at Stonyhurst 6·20 inches. Again, since before this evidence was given by the Author November had been reached, the average rainfall of October for the nineteen years was ascertained to be 4·84 inches, whilst that of 1880 was only 2·29 inches, and of this amount only 0·60 inch had fallen prior to the date of the stream gauging on the 19th.

It was argued, therefore, on all these grounds, namely, the low full year's rainfall; the low rainfall in the previous four

winter months; the low rainfall of August and September; and the exceptionally low rainfall of the nineteen days of October; that on the days the streams were gauged a very low, if not an absolutely minimum discharge, might fairly be anticipated. That, in fact, it could only be in exceptional seasons, occurring possibly once in a dozen years, and in the height of a hot summer, that less water would be found running down these streams than was gauged on the 19th and 20th of October, 1880. This being so, it was contended that neither in respect of flocks, herds, nor grouse, could the claimant be appreciably injured.

Competent valuers employed by the Corporation took this view of the case, and testified that the only grounds of claim that could be substantiated were for the pipe easements, for extra watching in the breeding season, and for slight injury to the fishing in Tarnbrook Wyre, and these items they valued at sums ranging between £730 and £1,592.

The claim having been £30,000, the highest valuation by the claimant's witnesses £29,700, and the lowest £16,035, the Arbitrator's award was £3,500.

The claimant's costs (payable by the corporation) amounting to £4,200 have been taxed down to about £1,200.

The Paper is illustrated by several drawings and maps, from which Plates 8, 9, 10, 11, have been prepared.

(Paper No. 1868.)

“Canal Navigation in Belgium.”¹

By A. GOBERT.

(Translated and abstracted by Alfred Bache, B.A., Assoc. Inst. C.E.)

THE first portion of this Paper deals with the improvements recently proposed for what the Author calls canals of *mean* section, in which the depth of water is not less than two metres nor more than three (say from $6\frac{1}{2}$ to 10 feet). The second portion treats of *maritime* canals, defined as having not less than five metres (say $16\frac{1}{2}$ feet) depth of water; and investigates the various plans lately brought forwards in Belgium for canals of this class. The expression “average annual traffic” is taken to denote the tonnage arrived at as the quotient when the total ton-miles resulting from a year’s traffic in both directions are divided by the length of the canal. “Freight” includes all expenses pertaining to towing, boats, boatmen, and return of empties. Interest on capital, maintenance of works, and working of locks, together make up the “tolls.”

I.—CANALS OF MEAN SECTION.

In reports on the improvement of canals of this class in France, drawn up in 1872–74 by M. Krantz, and in 1878 by the minister of public works, M. de Freycinet, the conclusion arrived at by both authorities was that in any country it was highly important, alike for agriculture and for other industries, that there should be a network of canals, running somewhat parallel to that of the railways, wheresoever there was altogether traffic enough to pay the interest on both the canal and the railway capital: to which the Author adds that, in order to ensure co-operation instead of competition, both modes of carriage ought to be under one and the same management, which he considers ought to be controlled by the government. The chief aim of improvements should be to bring about uniformity of section, which is sadly wanting in the present canals

¹ This Paper (appearing in the “Revue universelle des Mines,” 1881, vol. ix., pp. 356–400, 469–490; and vol. x., pp. 95–134), formed part of a competitive essay, which was written in 1880, on the Development of Belgian Commerce, and which was adjudicated a work of more than ordinary merit: eliciting the comment that, in dealing with the question of canal navigation, the accuracy of the calculations employed and the fairness of the views advanced were evidence of a thoroughly sound acquaintance with the subject.

in France and elsewhere, as pointed out both by M. Krantz and by M. Théophile Finet, a Belgian engineer. French canals are classed as "main" and "secondary," the former being under government administration, while the latter are leased with or without subsidy. The main canals are required to have 2 metres = 6½ feet depth of water, with locks 5·2 metres = 17 feet wide and 38·5 metres = 126 feet long. The administration of the main canals by the government is understood to imply their maintenance by the State, and the working of the locks, subject to the tolls; the option of the tractive power to be employed is also reserved to the government, which however undertakes no responsibilities of any kind in regard to the actual conveyance of the traffic. For the working of the canals it is considered essential in France that the bargees with their families should continue, as hitherto, to live in their boats.

In Belgium views have latterly been advanced which are altogether contrary to those current in France. In his book of 1878, M. Finet recommended single-width canals worked on a similar plan to railways, doing away with the bargees, and making up a train of barges with a tug in front and a steering barge in rear, all the intermediate barges having flat vertical ends, slightly rounded below water-line, instead of anything like prow and stern. Since the power required to tow a boat is independent of its length, the expense of towing would thereby be reduced to a minimum. The whole train might carry 1000 tons, in five to ten barges containing 200 to 100 tons each; its total length would be about 140 metres or 460 feet, and it would want only two men on the tug and either one or two men on the rear barge. The locks would have to be 150 metres or 490 feet long, in order to avoid breaking up a train.

Cost of Carriage by Canal and by Rail.—In advocating his own ideas, M. Finet charged railways and bargee-canal with not being able to carry goods cheaply enough. The Author proceeds therefore to examine the net cost of carrying heavy goods by the best ordinary canals on the bargee system, and by railway: and to show that M. Finet's single-width and long-lock scheme with train of barges would not carry more cheaply than could be done by the present system when improved as it ought to be. In his report of 1874, M. Krantz assumed that canal traffic, like that of railways, ought to pay, including interest and redemption, 5·65 per cent. on the capital sunk, which averages for canals 180,000 francs per kilometre (£11,500 per mile); it must also pay maintenance of works, and working of locks, which together are taken to average yearly 1450 francs per kilometre (£93 per mile); and further it must pay "freight" (as already defined), which he assumes as an

invariable charge of 1·5 centime per tonne-kilom. = 0·234 penny per ton per mile. On these assumptions it is readily shown in a tabular form how largely the net cost of canal carriage is affected by the total amount of the traffic: thus, with an average annual traffic of only 50,000 tonnes-kilom. (say 30,000 ton-miles) the net cost would rise to as much as 24·74 centimes per tonne-kilom. = 3·853 pence per ton per mile, which is as high as carting by road would be; whilst twenty times as much traffic, or 1,000,000 tonnes-kilom. (say 600,000 ton-miles), would bring the net cost down to only one-ninth, or 2·66 centimes per tonne-kilom. = 0·414 penny per ton per mile. To the freight charge of 1·5 centime per tonne-kilom. = 0·234 penny per ton per mile, derived by M. Krantz from the canals in the north of France, exception is taken by the Author, who examines separately the several items that go to make up the freight—towing, boats, boatmen, and return of empties.

Steam Towing.—On the Willebroeck canal, which runs north from Brussels past Willebroeck and enters the river Rupel opposite Boom, all boats except steamers are towed by a steam tug working on a chain. The length of the canal is 28 kilom. = $17\frac{1}{2}$ miles, divided into five levels; and the locks are large enough to take in six or seven boats at a time, along with their tug. The towing is done by a company, from whose scale of charges and year's balance-sheet the Author deduces 5 millimes¹ per tonne-kilom. = 0·078 penny per ton per mile as the actual price paid for towing, the total annual traffic amounting to 25,200,000 tonnes-kilom. (say 15,400,000 ton-miles). But if the actual dividends were reduced to the rate of 4 per cent., which prevails for Belgian government securities, and if certain economies were effected which he believes to be practicable, the Author considers the charge for towing might be brought down to 3 millimes per tonne-kilom. = 0·047 penny per ton per mile, including empties free.

Horse Towing.—On two Belgian canals, the Louvain and the Charleroi, horses are employed for towing. The Louvain canal is semi-maritime, with $3\frac{1}{2}$ metres = $11\frac{1}{2}$ feet depth of water, and runs north-west from Louvain to the river Senne, which flows into the Rupel about 1 kilom. or $\frac{5}{8}$ mile further north-west. Its length is 30 kilom. = $18\frac{3}{4}$ miles, divided into five levels; the total tonnage of the boats and ships passing through it in 1878 is estimated by the Author at 273,000 tons, and the charge for towing averages 6 millimes per tonne-kilom. = 0·093 penny per ton per mile. The Charleroi canal, winding northwards from Charleroi to Brussels by

¹ That is the one-thousandth part of a franc.

a circuitous route of 75 kilom. = 47 miles, is of small section, and its boats all alike carry only 70 tons; hence the charge for towing is higher, amounting to 8 millimes per tonne-kilom. = 0·125 penny per ton per mile. Including return of empties, the Author estimates that horse towing might be done on government canals for 5 millimes per tonne-kilom. = 0·078 penny per ton per mile; while Dr. Meitzen, a German authority, has arrived at an estimate of from 4·2 to 5·1 millimes = 0·065 to 0·079 penny.

Boats, Boatmen, and Empties.—The 110-ton boats in general use by the carriers on the Willebroeck canal make weekly the double journey from Brussels to Antwerp and back; the distance by the canal, the Rupel, and the Scheldt, is $45 \times 2 = 90$ kilom. = 56 miles there and back. The boatman gets 70 francs = 56s. per week for himself and his boat. With a full load both ways, this would give 7 millimes per tonne-kilom. = 0·109 penny per ton per mile. When the Charleroi canal is enlarged, the Author anticipates a large traffic right through from Charleroi to Antwerp, a distance of 120 kilom. = 75 miles; a single journey per week would then bring the cost down to 5·2 millimes = 0·081 penny. German estimates by Dr. Meitzen range from 4·8 to 6·4 millimes = 0·075 to 0·100 penny. Whence the Author takes 5 millimes per tonne-kilom. = 0·078 penny per ton per mile as the cost of boats and boatmen, with a full load both ways, travelling 17 kilom. or 11 miles per day, including all stoppages. One empty return in two double journeys is as much as occurs in Belgium: this is equivalent to making every journey with three-quarters of a full load, whereby the above figures would be increased one-third, giving 6·6 millimes per tonne-kilom. = 0·103 penny per ton per mile.

Net Cost of Canal Carriage.—Applying the foregoing estimates to an assumed average annual traffic of 1,000,000 tonnes-kilom. (say 600,000 ton-miles), the Author arrives at 18·2 and 20·2 millimes per tonne-kilom. = 0·284 and 0·315 penny per ton per mile as the net cost of canal carriage, with steam and horse towing respectively. These amounts are made up as follows:—

		Millimes.		Penny.
TOLLS	Interest and redemption, at 4 per cent.	7·2	per tonne-kilométrique, per ton per mile.	0·112
	Maintenance, and locking	1·4		0·022
FREIGHT	Steam towing	9·0		0·047
	Boats, boatmen, and empties	6·6		0·103
Totals, with Steam towing		18·2		0·284
Horse towing, excess over steam		2·0		0·031
Totals, with Horse towing		20·2		0·315

Net Cost of Carriage by Rail.—From French statistics of 1867 M. Krantz arrived at 38 millimes per tonne-kilom. = 0·592 penny per ton per mile as the actual minimum charge for the carriage of heavy goods by rail, which he considered might be subdivided nearly as follows:—

	Millimes.	per tonne-kilom.	Penny.
Locomotive power	9		0·140
Rolling stock	5		0·078
Wages and maintenance	5		0·078
Interest and general charges	19		0·296
	—		—
<i>Totals</i>	38		0·592
	—		—

Subsequently he gave 35 millimes = 0·545 penny as the minimum charge practicable. At this rate he argued that a canal could not compete with a railway, unless it could secure a traffic averaging yearly at least 600,000 tonnes per kilom. (say 370,000 tons per mile). But in the absence of railway communication a canal would pay with only one-quarter to one-sixth of that amount of traffic.

In Belgium, where interest on capital is about all the profit the State railways are expected to earn, the net cost of carriage comes nearer to the charge made for it. The lowest charge is stated by M. Sainctelette, the Minister of Public Works, to have occurred in 1878, and to have amounted to 31 millimes per tonne-kilom. = 0·483 penny per ton per mile. The coal traffic from the province of Hainault to Paris was charged in the same year 35·8 millimes per tonne-kilom. = 0·558 penny per ton per mile by the Northern Railway of France; notwithstanding this competition, the canal navigation of 283 kilom. = 177 miles from Belgium towards Paris had a coal ton-mileage amounting to nearly half as much as that by rail. M. Sainctelette concludes that, in spite of new or improved canals, the railways will continue to carry large quantities of coal and to earn an important revenue for the State; while at the same time, however low be the charge for carriage by rail, the freight by water can be made lower still. That 31 millimes = 0·483 penny is about the lowest charge practicable for goods traffic on the Belgian railways is confirmed, in the Author's opinion, by the fact that their passenger fares have lately had to be raised 5 per cent. in order to yield the required revenue. The canal charges, already arrived at, of 18·2 or 20·2 millimes = 0·284 or 0·315 penny, are therefore seen to be fully one-third less than the minimum charge for carriage by rail.

M. Finet's scheme of Single-width Canals.—The tempting prospect of towing a train of ten 100-ton barges with scarcely any more

power than would be required to tow only one of them, and the alluring advantages of speedily loading each separate barge, and of detaching and attaching barges at intermediate wharves along the canal's course, are considered by the Author to disappear when looked into practically. A single-width canal would lose the great advantage which the ordinary double-width canals now possess over railways, of allowing boats to stop at any spot whatsoever, for loading or discharging cargo. A regular time-table would have to be strictly enforced; all boats would have to be made up into trains, involving loss of time at starting; there would be delays at the turn-outs, where the canal was widened for allowing the return trains to pass; and steamers could no longer go where and when they pleased. Bridges and locks, being already of single width, could be built no cheaper; while the proposed long locks of 150 metres = 490 feet length, to take a train of barges, would cost vastly more than the present French locks of 38·5 metres = 126 feet length. Even with very few locks, a single-width canal would not come more than one-ninth cheaper than the ordinary canals of double width; at the outside therefore it would not take off more than 1 millime per tonne-kilom. = 0·016 penny per ton per mile from the tolls. Under the head of towing, the only possible saving would be in consumption of coal in the steam tugs, which on the Willebroeck canal costs about $\frac{1}{2}$ millime per tonne-kilom. = 0·008 penny per ton per mile; if half this were saved on a single-width canal, $\frac{1}{4}$ millime = 0·004 penny would be all the economy thereby effected. As for dispensing with barges on all except the tug and the rear barge of a train, the Author considers it would be practically impossible to work a train of rudderless barges round the bends of a canal, and a most tedious and difficult job to handle the barges separately at the wharves and docks where the train has to be made up or dispersed; moreover the cargoes would not get properly watched, with so few men to look after them. The total saving possible on a single-width canal, of $1\frac{1}{4}$ millime per tonne-kilom. = 0·020 penny per ton per mile, would be swallowed up, the Author believes, by the extra management expenses consequent upon having to organise the canal service on a similar plan to that of railways. He points out also that interest on original capital has been omitted from M. Finet's estimated cost of canal carriage, which is charged only with the interest on capital expended in improving the existing canals, thereby vitiating the comparison with carriage by rail; while the unexplained assertion that 1 millime would cover the "freight" on a single-width canal is met by the Author's foregoing analysis, which shows 9·6 millimes per

tonne-kilom. = 0·150 penny per ton per mile to be about the actual minimum. In preference to any such scheme as that of single-width canals, the Author recommends the plan of navigation already carried out upon the Willebroeck canal, where boats and boatmen are hired yearly by carrier firms, and goods are conveyed as safely and punctually (except in frosts) as by rail. This plan he expects will undergo a vast extension, as soon as ever there is a good system of canals reaching from Antwerp to Charleroi, Mons, and Paris, and from Antwerp to Ruhrort on the Rhine.

Canal carriage compared with Sea.—While long sea voyages, in which thousands of tons are carried thousands of miles, offer too great a contrast to canal navigation, the latter may very fairly be compared with short sea passages and coasting trips, in which a few hundred tons are carried only a few hundred miles. From London to Antwerp, a distance of about 350 kilometres or say 220 miles, the freight by steamer is 21·5 millimes per tonne-kilom. = 0·335 penny per ton per mile, which agrees very closely with the Author's estimate of 18·2 to 20·2 millimes = 0·284 to 0·315 penny for canal carriage. The canal charge covers maintenance of waterway and interest &c. on construction; the sea charge, while free from both of these, includes other costs not incident upon canals.

II.—MARITIME CANALS.

Terneuzen Canal.—Referring to the powerful advocacy of MM. Colson, De Maere-Limnander, and De Grandvoir, in favour of constructing ship canals in the provinces of Brabant, Flanders, and Liège, the Author points out that their arguments are altogether of a general character, and are not backed up with detailed estimates of profit and loss, such as ought to be made out beforehand in connection with each of the several projects. He recommends watching the results that will ensue from the deepening just commenced of the existing Terneuzen ship canal, constructed in 1824–7, which runs northwards 34 kilom. = 21 miles from Ghent to Terneuzen in the estuary of the Scheldt. The upper level of this canal, extending 20·854 kilom. say 13 miles north from Ghent to Sas-de-Gant (Ghent Lock), has only 4·4 metres or 14½ feet depth of water, so that no vessels of more than 4 metres or 13 feet draught can get up to Ghent; while in the lower or northern level of 13·187 kilom. say 8 miles length, the depth increases from 4·32 metres or 14¼ feet at Sas-de-Gant to 5·66 metres or 18½ feet at the sea-lock at Terneuzen, where vessels of 5·3 metres or 17¼ feet draught can accordingly enter at the lowest tides. The bottom is now to be deepened throughout the canal's

entire length from Terneuzen to Ghent, to a uniform depth of 4·02 metres = 13·2 feet below Dutch datum A.P.,¹ so as to give 6·5 metres = 21·3 feet depth of water in the upper level, and 6·05 metres = 19·8 feet in the lower; the two locks, at Ghent and at Sas-de-Gant, are to be made 0·25 metre = 10 inches deeper still than the new bottom, with a view to the canal being further deepened to that extent whensoever the time may come for a new sea-lock to be constructed at Terneuzen.

Competing Ports.—Six general considerations are advanced by the Author in respect to the question of constructing maritime canals. In the first place, the advantage of competing ports is illustrated by the virtual monopoly at present held by Antwerp, where all traffic (except rails and ores) that does not come in river boats has to be carted at a cost per ton of $1\frac{1}{2}$ franc = $14\frac{1}{2}$ pence and upwards; the consequence is that certain large works in the Liège district avoid Antwerp by making Terneuzen their port instead.

Avoidance of Transhipment.—Secondly, the minimum charge of $1\frac{1}{2}$ franc = $14\frac{1}{2}$ pence per ton for transhipment at Antwerp would carry the goods by rail a distance of 48 kilom. = 30 miles, taking the railway rate previously arrived at of 31 millimes per tonne-kilom. = 0·483 penny per ton per mile. The saving of transhipment will benefit any canal in the inverse ratio of its length.

Proximity of existing Canals.—Thirdly, it will not pay to make a ship canal through a district already served by an ordinary canal, unless there be traffic enough to ensure a profit after debiting the ship canal with the loss it will entail upon the existing canal, which is certain to be thrown idle.

Travelling night and day.—Fourthly, the present custom in Belgium is for canal boats to travel by day only; but they might safely do so by night also, provided it were arranged that the up and down traffic should go on alternate nights. In that way, for instance, the present six days' journey from Charleroi to Brussels would be completed in only four days, the boats travelling two alternate nights and stopping the other two. More men would then be wanted for the ordinary canal-boats, as well as for the locks; but ships have of course an ample crew already.

Sea-borne Commerce.—Fifthly, ship canals attract to sea-borne commerce capital which would not otherwise be so embarked. The importance of capital in this connection is illustrated by the success which has attended the Amsterdam ship canal, and which Flushing, despite her quays and cranes, so signally lacks. Had

¹ *Vide Minutes of Proceedings Inst. C.E.*, vol. lxii., pp. 4 and 82.

Brussels, out of her redundancy of capital, dowered Antwerp with adequate means of warehousing cotton and corn, the Author believes a highly lucrative trade in both these commodities might already have been secured to Belgium; and he looks forwards to the advantages which will accrue from rendering Brussels a large sea-port through the projected ship canal of 30 kilom. = 19 miles to the Scheldt.

Net Cost of Carriage by Ship Canal.—Sixthly, taking a 1000-ton steamer to burn coals to the value of 225 francs = £9 per day when doing her 360 kilom. = 225 miles in 24 hours at sea, this is equivalent to 62·5 centimes per kilom. = 9·58 pence per mile. On the Erie canal, with locks 8 kilom. = 5 miles apart, the goods steamers do 64 kilom. = 40 miles per 24 hours. Assuming only 60 kilom. = 37½ miles per 24 hours on ship canals in Belgium, and the same consumption for this lower speed as for the higher speed at sea, the coal burnt on the ship canal will cost 37·5 francs = £1 10s. per day. Interest, redemption, insurance, and wages, may be taken to make up a fixed charge of 400 francs = £16 per day. Hence the freight is altogether 437·5 francs = £17 10s. per day, or 7·3 millimes per tonne-kilom. = 0·114 penny per ton per mile; and adding one-third as before to allow for empties, the actual freight becomes 9·7 millimes per tonne-kilom. = 0·151 penny per ton per mile, or very closely the same as the freight previously arrived at for the ordinary canal-boats. According to their size, the proposed ship canals in Belgium would cost for construction and maintenance, some of them about twice and others about three times as much as the ordinary canals; their depths of water would be 5 metres or 16½ feet and 6¾ metres or 22 feet respectively, and they would be large enough for steamers up to 1000 tons and 3000 tons respectively. The tolls previously ascertained, of 8·6 millimes per tonne-kilom. = 0·134 penny per ton per mile on the ordinary canals, with an average annual traffic of 1,000,000 tonnes-kilom. (say 600,000 ton-miles), would therefore become 17·2 millimes = 0·268 penny, and 25·8 millimes = 0·402 penny for the same amount of traffic on the smaller and larger maritime canals respectively. The net cost of carriage on the two sizes of ship canals would accordingly stand as follows, in millimes per tonne-kilom. and pence per ton per mile:—

Depth of Water in Canal . . .		5·00 metres = 16·4 feet.	6·75 metres = 22·1 feet.
Tolls	17·2 millimes = 0·268 penny	25·8 millimes = 0·402 penny.	
Freight	9·7 „ = 0·151 „	9·7 „ = 0·151 „	
Totals .	26·9 „ = 0·419 „	35·5 „ = 0·553 „	

As examples of the advantages resulting from ships being able to make their way up to inland ports at a distance from the sea, the Author refers to the large amount of traffic passing up the Seine in sea-going vessels to Rouen, a distance of 124 kilom. = 77 miles inland from Havre. On the Terneuzen canal the tonnage going up to Ghent in ships was trebled from 1870 to 1878; while in the same period that going up the Scheldt to Antwerp was only doubled. The Amsterdam ship canal, of 28 kilom. = $17\frac{1}{2}$ miles length and 7 metres = 23 feet depth of water, has already, since its opening at the end of 1876, caused a rapid increase in the commercial importance of Amsterdam. From official statistics compiled for the Belgian Parliament¹ in 1878 by the late Baron Jacques Behr, the seven Belgian ports rank in the following order of commercial importance:—Antwerp, Ostend, Ghent, Louvain, Brussels, Bruges, Nieuport. Antwerp alone takes 85 per cent. of the entire sea tonnage of Belgium, leaving only 15 per cent. for the six secondary ports together. In the British Isles the proportions are 40 per cent. for London and Liverpool jointly, and 60 per cent. for the one hundred and twenty-two secondary ports. In France also the same proportions obtain: Marseilles and Havre together absorb 40 per cent., leaving 60 per cent. for the seventy-three secondary ports. The inference is that, if Belgium had secondary ports easily accessible for large ships, these secondary ports would enjoy a share of traffic corresponding with that of similar ports in other countries. The traffic at Antwerp by ships, railways, and river and canal-boats, is analysed by the Author; and the physical geography of the Belgian sea-coast and of the Scheldt estuary is described, which clearly points out the Scheldt as the great highway to the sea for Belgium.

Proposed Maritime Canals.—The Author examines in detail the commercial and engineering aspects of the several ship canals proposed within the last eight years for the provinces of Flanders, Brabant, and Liège. The Flanders project²—for the construction of a harbour and sea-lock on the coast at Heyst, and thence of two ship canals with 7 metres = 23 feet depth of water, one of 12 kilom. = $7\frac{1}{2}$ miles to Bruges, and the other of 50 kilom. = $31\frac{1}{4}$ miles to

¹ *Vide* "Travaux Hydrauliques," No. 174 of Belgian Parliamentary Papers, dated 24 May, 1878, containing detailed descriptions and illustrative plans of the projects for extending the sea commerce of Belgium; Plate 3 represents graphically the statistics here referred to.

² *Vide* "Travaux Hydrauliques," section 1.

Ghent, as proposed by M. de Maere-Limnander—is shown to hold out no prospect of financial success.

M. Colson's plan for maritime canals in Brabant¹—from the Scheldt to Brussels, Malines, and Louvain—would alter and utilise the existing Willebroeck and Louvain canals, enlarging them to $6\frac{3}{4}$ metres or 22 feet depth of water, with 20 metres = $65\frac{1}{2}$ feet width at bottom and $53\frac{3}{4}$ metres = $176\frac{1}{2}$ feet at surface, so as everywhere to allow two vessels to pass. Instead of both canals falling into the Rupel as at present, the Willebroeck or Brussels canal would be prolonged to enter the Scheldt just above the confluence of the Rupel, opposite Rupelmonde; the Louvain canal would join the Brussels canal at a little more than 8 kilom. = 5 miles from Brussels; and a branch of 8·8 kilom. = $5\frac{1}{2}$ miles would connect Malines with the Brussels canal. The distances from Antwerp would be 45 kilom. = 28 miles to Brussels, 61 kilom. = 38 miles to Louvain, and 34 kilom. = $21\frac{1}{4}$ miles to Malines. There would be five levels, as at present, for the total fall of 10·78 metres = $35\frac{1}{2}$ feet from Brussels to the Scheldt; and the locks would be 14 metres = 46 feet wide, with a clear length of 120 metres = 394 feet. A lengthened investigation respecting traffic leads the Author to the conclusion that the Brabant plan, besides being easy of execution, will prove from the very first a profitable undertaking, and will largely aid the development of Belgian commerce.

A maritime canal from Liège to the Scheldt, with 5 metres = $16\frac{1}{2}$ feet depth of water, is proposed by M. de Grandvoir, passing through Tongres, Diest, and Aerschot, and joining the present Louvain canal near Campenhout lock. Below this lock both the present canal and the Rupel would want deepening. The distance would be 127 kilom. = $79\frac{1}{2}$ miles by the new canal from Liège to Sennegat, the outlet of the Senne into the Rupel; and from Sennegat to Antwerp 28 kilom. = $17\frac{1}{2}$ miles by river: making a total of 155 kilom. = 97 miles from Liège to Antwerp by water, against the railway route of only 108 kilom. = $67\frac{1}{2}$ miles. The existing Campine canal from Liège to Antwerp, which takes a longer course northwards of the proposed route, would be laid idle by the ship canal. From traffic considerations which he investigates, the Author believes the carrying out of the Liège project could not result otherwise than in loss.

Conclusion.—While engineering talent has for half a century past been brought to bear upon the development of the railway

¹ *Vide* "Travaux Hydrauliques," section 3.

system, canals have been almost neglected. The Author has aimed at showing the importance of their now receiving very careful attention; he recommends examining the present state of canal navigation in other countries, and watching closely the Canadian ship canals, as well as the ordinary canals in America, particularly the Erie canal. Great results may yet be achieved, he is confident, by the scientific study of canal navigation.

(*Paper No. 1844.*)

“The Burning of Town-Refuse at Leeds.”

By CHARLES SLAGG, Assoc. Inst. C.E.

IN large towns it is necessary to adopt some regular system of removal and disposal of the cinders and ashes of house-fires, and of the animal and vegetable refuse of the houses, and, in short, of everything thrown away which cannot be admitted into the sewers. In towns where the excreta are separated by means of water-closets, the disposal of the other refuse presents less difficulty, but still a considerable one, because the animal and vegetable refuse is not kept separate from the cinders and ashes, all being thrown together into the ashpit or dust-din. The contents therefore cannot be deposited upon ground which may afterwards be built upon, although that custom obtained generally in former times. Hence the refuse has been removed to a depot where that wretched industry is created of picking out the other parts from the cinders and ashes.

But in towns unprovided with water-closets, or so far as they are not adopted in any town, where the privies are connected with the ashpits, and where, consequently, the excreta of the population are added to the other contents of ashpits, the difficulties of removal and disposal of the refuse are much increased.

Where the privy-ashpit system is in use—as it still is to a large extent—as much of the contents of the ashpits as can be sold at any price, however small, are collected separately from the drier portions, and sent out of the town as manure, but what remains is still too offensive to be deposited on ground near the town; and when it is attempted to collect the excreta separately by the pail-system, the process is no less unsatisfactory. These difficulties led to the adoption, under the advice of the late Mr. A. W. Morant, M. Inst. C.E., the Borough Engineer, at Leeds, of Fryer's method of destruction by burning—that is, of the dry ashes and cinders and the animal and vegetable refuse. The Author was Mr. Morant's assistant. The first kiln was constructed at Burmantofts, $1\frac{1}{2}$ mile from the centre of the town in a north-easterly direction, and has been in use since the beginning of the year 1878. In 1879 another kiln was constructed at Armley Road, a mile from the

centre of the town in a west-south-westerly direction, which has been in use since the beginning of 1880.

Each destructor kiln has six cells, three in each face of a block of brickwork 22 feet long, 24 feet through from face to face, and 12 feet high. Each cell is 8 feet long and 5 feet wide, arched over, the height being 3 feet 4 inches, and both the bottom and the arch of the cell slope down to the furnace doors with an inclination of 1 in 3. The lower end of each cell has about 26 square feet of wrought-iron firebars, the hearth being $4\frac{1}{2}$ feet above the ground.

FIG. 1.



There are two floors, one on the ground level, a few feet only above the outlet for drainage, the other floor, or raised platform, being 15 feet above it. The refuse is taken in carts up an incline of 1 in 14 on cast-iron tram plates to the upper floor, and deposited upon and alongside of the destructor, and is shovelled into a row of hoppers at the head of the cells. These hoppers are in the middle of the width of the destructor, and each communicates with a cell on each side of it. The refuse is always damp, and often wet, and, after being put into the cells, is gradually dried by the heat reflected upon it from the firebrick arch of the cell, before it descends to the furnace. This distinguishes the system from the common furnace, and enables the wet material to be burnt without other fuel. No fresh fuel is used after the fires are once lighted. The vapour passes off with the gases of combustion into a horizontal flue between the two rows of cells, through an opening at the head of each cell, alongside that through which the refuse is fed into it, the two openings being separated by a firebrick wall. The refuse is prevented from falling into the flue by a bridge wall across the outlet opening, over which the gases pass into the flue.

Between the destructor and the chimney a multitubular boiler is placed, which makes steam enough for grinding into sand the clinkers which are the solid residue of the burnt refuse. At Burmantofts an old chimney was made use of, which is but 84 feet high; but at Armley Road a new chimney was built, 6 feet square

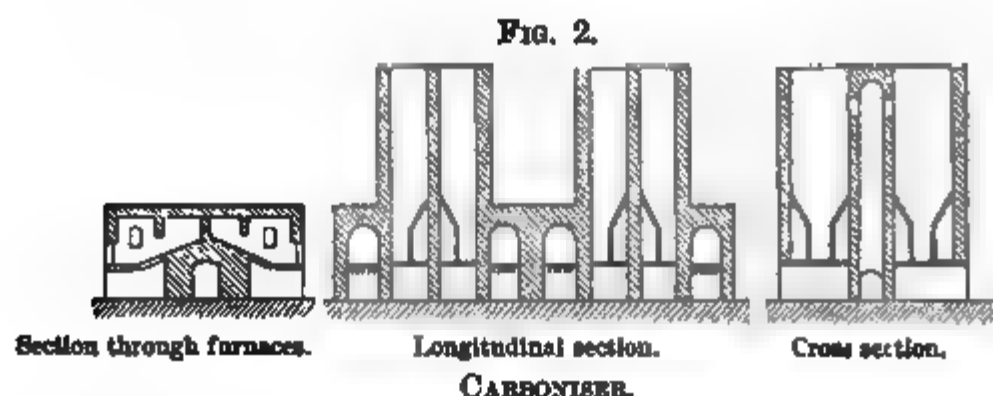
inside and 120 feet high. It is necessary to make the horizontal flue large; that at Armley Road is 9 feet high and 4 feet wide. A large quantity of dust escapes from the cells—about 7 cwt. a month—and unless the velocity of the air in the flue between the destructor and the chimney were checked, the dust would be carried up the chimney and might cause complaints; as, indeed, it has done with the 120-feet chimney, but whether with any substantial grounds is uncertain. The dust is removed from the horizontal flue or dust chamber once a month. Experience seems to indicate that there should also be some sort of guard or grating to prevent the entry into the chimney of charred paper and similar light substances which do not fall to dust, and which are sometimes carried up with the draught.

A six-celled destructor kiln burns about 42 tons of refuse in twenty-four hours, leaving about one-fourth of its bulk of clinkers and ashes. The clinkers are withdrawn from the furnaces five times each day and night, or about every two-and-a-half hours, into iron barrows, and wheeled outside the shed which covers the destructor, and when cold are wheeled back to the mortar mills, of which there are two at each depot, each having a revolving pan 8 feet in diameter, with 27-cwt. rollers, the pan making twenty-two revolutions a minute. Forty shovelfuls of clinkers and twelve of slacked lime make 7 cwt. of mortar in thirty-five minutes in each pan, which is sold at 5s. 6d. per ton. The engine driving the two mortar-mills has a 14-inch cylinder, 30 inches length of stroke, and makes sixty revolutions per minute with 45 lbs. steam-pressure per square inch in the boiler, when both mortar mills are running. The boiler is 11 feet long, 8 feet in diameter, and has one hundred and thirty-two tubes 4 inches in external diameter, which, together with the external flues, are cleaned out once a month.

At first sight it would probably appear that no good mortar could be made from such refuse as has been described, but having passed through the furnace the clinkers are of course perfectly clean, and with good lime make a really strong and excellent mortar. They are also largely used for the foundation of roadways.

The number of men employed is as follows:—Two furnacemen in the day time and two at night. They work from midnight on Sundays to 2 p.m. on Saturdays, the fires being fully charged and left to burn through the Sundays. One foreman, who attends also to the running of the engine, and one mortar-man. A watchman attends while the workmen are off.

In addition to a "destructor," there is, at the Burmantofts depot, a "carboniser" kiln, in which the sweepings of the vegetable markets are burnt into charcoal. The "carboniser" consists of eight vertical cells, in two sets or stacks of four, separated by a



space containing two double furnaces, back to back, there being a double furnace also at each end of the eight cells. Each of the stacks of four cells is 15 feet 6 inches high; the ends and middle parts, forming the tops of the furnaces, being 6 feet high. The block of brickwork containing the eight cells and furnaces is 26 feet 6 inches long and 12 feet 4 inches wide at the floor level. Each cell is 3 feet 6 inches by 2 feet, and about 10 feet deep, with a chamber below about 3 feet deep, into which the charred material falls and is completely burnt. The top of the cells is level with the upper platform, and they are fed through a loose cover, which is immediately replaced. Inside the cells cast-iron sloping shelves are hung upon the walls so that their upper edges touch the walls, but the lower edges are some inches off, so that the hot air of the furnaces passes upwards behind the shelves, round the four sides of the cell in a spiral manner, and out near the top into a vertical flue, which conducts it down to the horizontal flue at the bottom, which leads to the chimney. The charcoal is withdrawn from the bottom of the heating chamber through a sliding plate 2 feet above the floor, and is wheeled red hot to the charcoal cooler, which is a revolving cylinder, nearly horizontal, kept cool by water falling upon it, and delivers the charcoal in two degrees of fineness at the end. It is worked by a small attached engine, supplied with steam from the boiler before mentioned. Each cell of the carboniser can reduce to charcoal 50 cwt. of vegetable refuse in twenty-four hours, but at Leeds not quite so much is put through. The quantity of market refuse passed through six cells of the carboniser varies from 3 to 10 tons a day, and averages about $4\frac{1}{2}$ tons, from which 15 cwt. of charcoal is obtained. The fuel for burning the charcoal is derived from the ashpit refuse, some selected loads being for

that purpose passed over a sloping screen fixed between the upper platform and the furnace floor, the fine ashes which pass through the screen being taken away to the manure heaps, and the combustible parts to the furnaces of the carboniser. In this way a good deal of ashpit refuse is got rid of; it is often $\frac{1}{12}$ part of the whole quantity.

The carboniser and the destructor are set 33 feet apart, to allow room for drawing the furnaces and for the mortar mills, but the space is hardly sufficient. One man is employed in attending to the carboniser.

Besides the openings at the top of the "destructor" through which the ashpit refuse is fed into the cells, there is a larger opening in each cell, kept covered usually, through which bed mattresses ordered by the medical sanitary office to be destroyed can be put into the cells. These openings are midway between the central openings and the furnace doors, and whatever is put into the cells through these comes into immediate contact with the fire. Advantage is taken of these openings for the destruction of dead animals and diseased meat, and as much as 20 tons in a year have been passed through the destructor.

The whole works are roofed over. The lower floor is open on two sides, but the upper one is closed in, with weather boarding at Burmantofts and with corrugated iron at Armley Road. At the former place the works were in some measure experimental, and the platform was constructed of timber, but at Armley Road it is of plate-iron girders, with brick arching, weight being considered advantageous in reducing the vibration of carting heavy loads over it.

The cost of each depot has been £4,500, exclusive of land, of which about an acre is required for the destructor, carboniser, inclined road, weigh office, and space. A supply of water is necessary, a good deal being required for cooling the clinkers. The population of the two districts belonging to these works is about 160,000.

The Author has no longer any connection with the works described, and for the recent experience of their working he is indebted to Mr. John Newhouse, the superintendent of the sanitary department of the Corporation.

OBITUARY NOTICES.

Mr. FRANCIS HAWKES was the eldest son of a father bearing the same Christian name, who practised as a Civil Engineer at Reading, where Mr. Hawkes, jun., was born on the 18th of August, 1818. After having received a good general and classical education, he was for some years under his father's charge as a pupil.

In the busy engineering years, from 1843 to 1847, he was wholly engaged on surveys and setting out of many important railways, including the Eastern Union and the London and North-Western, and at Clitheroe, Yorkshire; also in drawing up cases for parliamentary agents, and giving evidence in committees of the Houses of Lords and Commons upon railway bills; he was generally successful in these contests, displaying great ability.

During the years 1847 to 1851 Mr. Hawkes was occupied on enclosures, schemes for drainage and waterworks, and other private engineering and architectural practice in Berkshire.

In 1851 he was elected to the office of Borough Surveyor to the Corporation of Reading, and he held the appointment up to the time of his leaving England for India in 1856. During his tenure of the office he competed for and obtained the prize offered by the Reading Local Board of Health for a design for laying out the public gardens, and in 1853 he competed for and was awarded the first prize for designs for the Reading Corn Exchange and markets, which he subsequently erected in conjunction with the second prize-holder.

In May 1856, Mr. Hawkes was appointed by the Great Indian Peninsula Railway Company to the engineering staff in Bombay. For the first ten years he was occupied in surveys and setting out portions of the line, and in the preparation of the designs, estimates and specifications and detailed drawings for all the works in connection with the stations and locomotive depots works, for the entire line of railway. In the latter capacity he came under the notice of the chief engineer, Mr. James J. Berkley, M. Inst. C.E., and received rapid promotion in the service. Nine months after he joined, in March 1857, he was rewarded by promotion to second class assistant engineer, and again to first class assistant engineer in May 1860. In April 1868, he was placed in charge of the open line and works in progress at Bhosawal Junction, including the schools and new halting station which he had previously designed.

He continued to serve the Great Indian Peninsula Railway Company till January 1870, when, owing to the reductions consequent on the completion of the undertaking, he left that service. Soon after this he became agent to Messrs. Reid and Mitchell, the contractors for the reconstruction and maintenance of the Nagpore branch of the Great Indian Peninsula Railway, building new bridges and other works, and he also had charge of the maintenance of the line between Buduavia and Wurdali. This engagement ceased with the termination of the contract, and on the 1st of February, 1872, he joined Messrs. Hood, Winter and Mills, as contractors' engineer, and subsequently became their agent in charge of the construction works of the Ghât subdivision of the Holkar State Railway, remaining with the firm until the resumption of the contract by the Government of India in January 1874.

On the 1st of October, 1877, Mr. Hawkes was appointed district engineer of the Dacca district in Bengal (with the powers of an executive engineer), where for three years he was extensively employed in the construction and improvement of the road and water communications in that district. He erected a large iron screw-pile bridge over the River Toongee, which was the first of the kind built in that part of India. He also strengthened the anchorages and the road approaches of the suspension bridge which crosses the Dholye Khall, and generally improved its appearance.

During the summer of 1880 his mind was sorely taxed in connection with his work, producing a constant strain, which it was clear for some time was gradually undermining his naturally strong constitution; this state of health was aggravated by an illness which was brought on by serious injury sustained during a violent storm on the dangerous River Pudda or Ganges, when his boat was stranded. Mr. Hawkes was then on tour in the "Mofussil." Latterly he was confined to his bed for nearly three months, and his illness terminated fatally at Dacca on the 10th of October, 1880, in the sixty-second year of his age, to the great regret of his colleagues and friends, by whom he was much respected, both for his professional attainments and for his genial personal character. His conduct in business matters was marked by the highest honour and integrity, and he always aimed at perfection in all the works on which he was engaged.

Mr. Hawkes was elected a Member of the Institution of Civil Engineers on the 3rd of December, 1867.

MR. ROBERT MALLET¹ was born on the 3rd of June, 1810, in Dublin, where his father, John Mallet, originally of Devonshire, had established a brass and copper foundry. Young Mallet was at first a weakly child, but outgrew his ailments and became of very strong constitution. Until the age of sixteen he was educated at Bective House, a well-known school in Dublin, then kept by the Rev. G. N. Wright. On leaving the care of Mr. Wright he made his first visit to the Continent, in the company of the Rev. C. Barden, clergyman of the parish in which he lived, and of his future brother-in-law, Mr. William Watson, Assoc. Inst. C.E. In December 1826, he entered at Trinity College, Dublin, remaining there until he took his A.B. degree, four years later. During all this time he paid particular attention to engineering matters, but he was especially fond of chemistry, in which he attained marked proficiency. When only a little over twelve years of age he occupied so much of his time in boyish experiments and in making unsavoury chemical mixtures, that a small room was set apart as his laboratory, and whenever his mischievous pranks had to be corrected, the severest punishment was found to be his banishment from this elysium for a term proportioned to the magnitude of his offence.

After leaving college he spent a good deal of time in his father's works, and visiting engineering establishments in England at every opportunity, taking, at the same time, practical out-door lessons in surveying and levelling from Mr. J. J. Byrne. The rapidity with which he acquired practical engineering was remarkable.

In the year 1831 Mallet made an extended tour on the Continent in company with Mr. Purser, of Rathmines Castle, and Mr. Friedlozius, a Swedish Professor of Mathematics, under whose tuition the young engineer had been. On his return he became a partner in his father's works, and soon assumed the responsible charge of the Victoria Foundry, and the attached fitting and machine shops, and expanded the whole into a large concern, which in a few years absorbed all the engineering work of note carried out in Ireland.

One of his first works of importance, interesting for its originality, was the raising and sustaining of the roof of St. George's Church, Dublin. This roof, a massive construction, weighing 133

¹ The substance of this memoir is derived from information furnished by Dr. J. W. Mallet of the University of Virginia, largely supplemented by notices in the *Engineer*, of November 11 and 18, 1881.

tons, had failed, owing, as was supposed, to the use of the short timbers necessitated when it was built, the usual sources of supply being closed by reason of the great war. The walls of the church were bulged, and were in such a dangerous state, that it was proposed to unroof the building and put it up afresh. Mallet, however, offered, with due guarantee in case of failure, to raise and sustain the roof without damage to the ceiling. This he successfully accomplished by employing screw-jacks, which, being worked simultaneously, lifted the whole roof clean off the wall plates. A strong iron truss framing was then attached, and the whole suspended from it. A description of this work was presented to the Institution,¹ for which the Author received a Walker premium. In 1841 Mallet constructed a manumotive engine to carry the mails between Kingstown and Dublin. It was worked by eight men, and made the trip (about 5 miles) each way in twenty minutes. He also constructed a fine 40-ton crane for the Kingstown Wharf.

At this time the celebrated firm of brewers, Messrs. Guinness and Co., began to consult him upon various matters, and amongst other things he did was to give them a supply of water by boring a 4-in. hole through the solid rock at the bottom of a well that had given out, and then firing a charge of powder therein, by which the rock was shattered, and a supply of water obtained which has never since failed. He also constructed a machine worked by steam for washing casks, and erected a very large sky cooler for the brewery, which was then rapidly increasing in fame. Steam engines of various sizes were made in the works from his designs. The barrel-washing machines were also made for Messrs. D'Arcy and Messrs. Manders and Co. Steam printing and other machinery was made for Messrs. Grierson, then King's printers, and for the 'Dublin Freeman's Journal' and the 'Irish Times.'

In 1836 important works were being carried out by the Shannon Commissioners, Sir John Burgoyne being then the Government engineer, and owing to the skill of its junior member, which was becoming known throughout the country, Mallet's firm secured the contracts for the construction of a large number of bridges, including the swivel bridges over the Shannon at Limerick, Banagher, Portumna, Athlone, and Shannon Harbour. All the sluices and other apparatus were also made by the firm from designs for Robert Mallet.

Besides the varied work which was being carried out from these designs in the Victoria Foundry in 1837, he turned his attention

¹ *Vide Minutes of Proceedings Inst. C.E.*, vol. 1., p. 94.

to the hydraulic ram, and produced a form of that motor which was employed on the Dublin and Kingstown Railway for forcing water to tanks for the engines.

In May 1839, he was elected Associate of the Institution of Civil Engineers, proposed by Sir W. Cubitt, and seconded by Thos. Rhodes and Francis Bramah, and he was transferred to the class of Member three years afterwards at the recommendation of Sir J. Burgoyne, Mr. Fairbairn, and Mr. Vignoles. During this year the business at the Victoria Works was increasing, but in spite of this and severe family troubles, he managed to find time for experimental and literary work. The handsome tower gate entrance to the Duke of Abercorn's castle grounds was designed and erected by him for the father of the present duke. The gate when first erected was opened and closed by the lodge keeper from within the lodge. A working model of this gate is still to be seen in the duke's castle. At this time also his scientific knowledge was called into play in devising extensive ventilating and heating apparatus for a large number of public buildings, upon which he had to report. Amongst the buildings ventilated and heated from his designs were Dublin Castle and chapel, the Records Office, Law Courts, and numerous prisons and poor houses. In these the heating was effected by hot water, and the apparatus is in working order to this day. In 1840 he turned his attention to the supply of water to Dublin. He surveyed the river Dodder in 1841 at his own expense, and had plans made with a view to furnishing Dublin with pure water, and to supply the paper and other mills in summer time. All the paper mills were stopped in summer, but he proposed to remedy this by constructing six large reservoirs at different levels along the Dodder, so to store up and supply the water which caused floods and ran to waste in the Liffey.

In 1840 Mallet began to make beam engines of considerable power, such as those erected at the Ringsend Dock Mills of Messrs. Hastings and Carter, but the Irish market for steam engines was not more extensive then than now, and he turned his attention more to railway and civil engineering work; he also spent some time in his old college, for which he designed, erected, and fitted out the new laboratory for Dr. Apjohn. His taste in designing ironwork of an architectural character was also well shown in the circular stairs erected on each side of the chancel in Trinity College Chapel, and in the much admired palisading and railing bounding the College from Provost House in Grafton Street, through the whole length of Nassau Street, to Clare Street. The numerous illustrations of failure in the attempt to produce an

iron palisading of pleasing design shows that, though always looked upon as a small matter, it is not a task which can be satisfactorily discharged without some architectural taste.

It is worth remark that the three large 36-man power fire engines still used by the Dublin Corporation were made from his designs at the Victoria Foundry in 1841. In 1842-43, the shops were very full of the work to which the drainage operations then in progress and the railway system then fairly largely conducted, and at the same time such work as the construction of the Limerick dock gates, with 80 ft. opening and 24 ft. depth, formed part of the operations carried out under him. Railway signals and ovens for the production of coke for locomotives also employed his workmen. The atmospheric railway also employed much of his attention. He advocated the employment of large vacuum chambers to be exhausted by small engines running constantly, instead of the very large engines which were necessary under the system in use. The vacuum chambers thus proposed would have served the same purpose as the accumulator used for hydraulic machinery, and would have been very economical. The atmospheric system failed, however, owing to its want of flexibility and its costliness.

In 1845-6 he designed and erected the terminal station of the Dublin and Drogheda Railway; the large polygon engine-shed, with a hydraulic turntable in the centre; the Kingsbridge passenger sheds, and all the workshops and other buildings for the Great Southern and Western Railway; the engines and machinery for the Castlecomer Coal Mines, Co. Kilkenny; a 40-ft. overshot water-wheel and machinery for Mr. McDonald's paper-mills in Sagart, Co. Dublin, besides numerous other railway stations. Of this work, the Nore Viaduct should be mentioned, as the design for this, a wooden structure, though nominally prepared by Captain Moorsom, was re-designed by Mallet, as failure might have resulted from following the original drawings. The bridge was 200 feet in span, the main girders or wood trusses being 22 feet in depth, constructed of Canadian *hacmatac*, a wood very similar to pitch pine, but not possessing the strength of that material. Six hundred tons of timber were used in its construction, and during the erection a flood rise of 5 feet 9 inches took place in one night, bringing down cots and hay which rested against the staging, and the whole structure only just missed being wrecked in consequence. The timber trusses were replaced in 1876 by an iron lattice girder, constructed by Messrs. Courtenay, Stephens, and Bailey, from designs by Mr. R. Galwey, C.E. Moorsom's whole design

was considered by Mallet to be a mistake, as the situation was eminently well suited for a three-arch masonry bridge.

In 1849, he designed and constructed the iron station roofs at Belfast, Portadown, and Armagh. He also constructed the large engine-shed of the Lancashire and Yorkshire Railway at Miles Platting, of which Mr., now Sir, John Hawkshaw, was Engineer-in-chief. This was known as the Irish shed, and in the following year he eclipsed this performance by the construction of the Wakefield passenger shed for the same Company. The main roof is 95 feet in span and 750 feet long, and the whole structure was erected without any interruption to the traffic. That these structures should be made in Ireland excited great surprise at the time, but there were not so many firms then as now who could undertake that class of work.

The Fastnet Rock Lighthouse from the designs of Mr. George Halpin, then Engineer to the Port of Dublin, was built by Mallet in 1848-9. The tower is 63 feet 9 inches from base to gallery, and the lantern, of brass, is 30 feet high.

About the year 1840 he had commenced some experiments with the buckled plates, by which his name is well known to many ignorant of his connection with science and the arts. The buckled plate, patented in 1852, was one of the most successful of his inventions in a commercial sense, although in most other men's hands it would have been worth a hundredfold what it ever was to him. It was one of Mallet's faults that he had little commercial tact. As it was, however, the buckled plates were very extensively used in this country and abroad. They formed, perhaps, the best floor ever made, combining the maximum of strength with the minimum of depth and weight. They were employed on the Westminster and other London bridges, one of which was floored at Mallet's cost, owing to his own laxity in accepting verbal assurances from a contractor from whom the most stringent conditions should have been secured. He received a prolongation of the patent in 1866. He subsequently took out patents for buckled plate railway sleepers, and on the Bolivar Railway sixty miles of these cross-sleepers were laid by Messrs. Brunlees and McKerrow.

In 1850 he turned his attention to the construction of large guns, and first practically investigated the physical conditions involved in the construction of ringed ordnance, and in 1854 designed his monster mortars for throwing 36-inch shells.¹ Two

¹ Transactions of the Royal Irish Academy, 1856; and separately in book form, 4to., London, 1856. Longman and Co.

of these mortars were constructed for use at the Siege of Sebastopol, but were not used owing to peace having been proclaimed before the large iron rafts, specially designed for their reception, were ready.

The 70-ton sheerlegs at the Victoria (London) Docks were built by Messrs. C. J. Mare & Co., of Blackwall, from Mallet's designs. With the completion of the trunk lines in Ireland the work required to keep going such a concern as the Victoria Foundry gradually became scarce. Ironworks had so increased in number and variety in England and Scotland, that after importing iron and coal into Dublin prices became too high to permit profitable competition with English and Scotch firms. The failure to obtain the contract for pipes for an extension of the Dublin Waterworks determined the closing of the works after Mallet and his father had, as they thought satisfactorily, shown that such an establishment could not be maintained in Ireland.

In 1861 Robert Mallet gave up his house at Glasnevin, in Dublin, and came to London, when he opened an office in Westminster and practised as a consulting engineer, also attending to his patents. He edited the "Practical Mechanics' Journal," besides contributing largely to "The Engineer," and gave evidence as a scientific witness in patent cases. In 1863 he was employed by the proprietors of the Hibernia and other collieries in Westphalia to report on the best means of sinking and ventilation of their pits, with which they had encountered considerable difficulty. A year later he became associated with Mr. J. S. Burke in the scheme known as the Dublin Trunk Connecting Railway. The Act was obtained and the works of the railway fairly started, but, owing to some commercial and legal difficulties, they were stopped in 1866, after a large sum of money had been expended on the excavation and masonry of the shaft on the southern side of the Liffey for the tunnel under that river. When the East London Railway was about to seek powers to use the Thames Tunnel, Mallet was called in to report on its strength and condition, and on the possible effect the establishment of the railway so near the Royal Observatory, at Greenwich, might have upon the taking of Astronomical observations. The thorough tests and examination, besides palometric observation, made by him established the perfect security of the tunnel for railway traffic, as well as its non-liability to be injurious to the Observatory. This was probably the latest engineering work in which Mallet was engaged, the remainder of his career being confined to literary labour and to his consulting practice.

This account of Robert Mallet's business engagements is, however, but a portion, and not the most important portion, of his working career. An ordinary man might well be satisfied to show such a record of successful practical work, but the contemplation of Mallet's literary labour, largely achieved in his spare time, suggests the reflection that as a writer alone he claims the abundant recognition of the profession. It is perhaps rather in this capacity, and as a man of science, than as a skilful and original engineer, that his reputation is founded. The Royal Society's "Catalogue of Scientific Papers," which does not give those of a technical character, contains the titles of no less than seventy-four written by him down to 1873. His more important works include three Reports to the British Association (1838-1840-1843) on the action of sea and river water under various conditions upon cast- and wrought-iron; a Report to the same body (1849) on an experimental inquiry on railway bar corrosion; papers on the physical properties of definite alloys of copper with tin and zinc;¹ three Reports on the construction and working of atmospheric railways;² papers on principles and practice of the application of water power;³ memoir on the physical conditions involved in the construction of artillery of large calibre (1855)⁴—this representing a research in connection with the construction by Government of two 36-inch mortars from his designs, and under his superintendence; paper on the corrosion and fouling of iron ships;⁵ numerous and important papers on earthquakes, the rate of propagation of earthquake waves, volcanoes, and the source and mechanism of volcanic energy;⁶ the article on "Seismology" in the "Admiralty Manual of Scientific Engineering;" a special Report to the Royal Society on the expedition into the Kingdom of Naples to investigate the circumstances of the great earthquake of 16th December, 1857;⁷ an elaborate contribution to the literature of volcanic geology, entitled "Volcanic Energy; an attempt to develop its true origin and cosmical relations;"⁸ numerous editorial and other articles in

¹ Proceedings Royal Irish Academy, 1840-44.

² Weale, Quarterly Papers, 1845.

³ *Ibid.*, 1849.

⁴ Transactions of the Royal Irish Academy, 1856; and separately in book form, 4to., London, 1856. Longman and Co.

⁵ Read at session of Institution of Naval Architects, 1872.

⁶ Philosophical Transactions, 1861, 1862, 1873. British Association Reports, 1850-54, 1858. Proceedings of the Royal Irish Academy. Philosophical Magazine. Quarterly Journal of the Geological Society, &c.

⁷ Published in two vols., 8vo., in 1862. London: Chapman and Hall.

⁸ Phil. Trans., 1873.

“The Engineer” and “Practical Mechanics’ Journal;” reports on the Heaton method of making steel; on the International Exhibitions of London, 1851 and 1862 (being a juror in the case), and Paris, 1867, &c.

In January 1842 he was awarded a Walker Premium of the Institution of Civil Engineers, and in 1859 a Telford Medal and Premium; in 1862 the Cunningham Medal of the Royal Irish Academy, and in 1877 the Wollaston Gold Medal of the Geological Society.

After a life of unusually sound health and active occupation, in the winter of 1871-2 his eyes suffered from a severe attack, which gradually impaired and, after some time, practically destroyed his sight for all other purposes than merely guiding his movements, although he continued to accomplish much mental work with the aid of an amanuensis. In November 1880 he was attacked by diffuse cystitis, and after a year of much pain, patiently and courageously borne, with continuous confinement to bed, he died peacefully on the 5th of November, 1881.

In addition to Mr. Mallet’s connection with this Institution he was a Fellow of the Royal Society, and was also a member of the following scientific institutions and professional bodies at home and abroad: the Royal Irish Academy (1832), the British Association (1835), Institution of Civil Engineers of Ireland (1836 and President 1866), the Chamber of Commerce of Dublin (1837), Royal Geological Society of Ireland (1847, President), the Royal Scottish Society of Arts (1840), Academy of Science, Arts, and Belles Lettres of Dijon (1853), the Royal United Service Institution (1857), the Geological Society of London (1859), the Royal Philosophical Society of Göttingen (1859), and of several minor societies.

MR. WILLIAM MILNOR ROBERTS¹ was one of the oldest and most active members of the engineering profession in the United States. He was of Quaker descent, and was born in the City of Philadelphia on the 12th of February, 1810. His education was received in the best private schools of that city, and he devoted two terms to a special course in mathematics under Professor Joseph Roberts. He also pursued a course of architectural

¹ This memoir has been compiled from a notice in the *Rio News*, supplemented by details contained in obituaries in the American engineering journals, circa July 1881.

drawing in the first school established by the Franklin Institute under Mr. John Haviland, a noted architect of that day. On leaving school he continued his studies, principally in mathematics, of which he was very fond, during the winter months, the summer being spent in surveying.

Owing to his aptitude for mathematical studies and investigations, his father's friend, Samuel Mifflin, then president of the Union Canal Company of Pennsylvania, advised his adoption of the profession of civil engineering, an advice which he very wisely followed. His first employment was on the Union Canal, of Pennsylvania, in the spring of 1825, he being then in his sixteenth year. His duties were those of chainman to the eminent canal engineer, Canvass White, and the chief of the party to which he was attached was Sylvester Welch. His progress in his profession is shown by the fact that at the age of eighteen he was promoted by Mr. White to the charge of the most difficult section of the Lehigh Canal, extending from Mauch Chunk down for a distance of sixteen miles. In 1829 he published a description of the Lehigh Canal in "Hazard's Register."

It was Mr. Roberts' rare good fortune to have been connected with the first railway enterprises in the United States, his career as an engineer being thus contemporaneous with the beginnings and growth of that great agent in modern civilisation. Railway engineering in the United States began, in a crude way, in 1826 at the Quincy granite quarry, a tramway being then constructed for the transportation of stone from the quarry to the water, a distance of three or four miles. The first railway of any consequence, however, was the Mauch Chunk Gravity Road, nine miles in length, between the summit of Broad Top Mountain and the head of the Mauch Chunk inclined plane. The first passenger car in the United States was put on this road in the early summer of 1827, and Mr. Roberts was one of the passengers on the first trip down the line. With the development of railways Mr. Roberts grew into eminence as an engineer. From his initiation as a chainman, just one year before the first line of rails was laid in the States, his career was one of steady, substantial growth until the closing hours of his life.

In the course of his long career of fifty-six years, Mr. Roberts held so many and so varied positions of trust and responsibility, that a bare enumeration of them is all that can be here given. In 1829 Mr. Roberts' connection with the construction works of the Union and Lehigh Canals was brought to a termination, and in 1830 he was appointed resident engineer of the Union

Railroad and a feeder of the Union Canal. In 1831 he was appointed senior principal assistant engineer under his friend and preceptor, Sylvester Welch, chief engineer on the Allegheny Portage Railroad in Pennsylvania. This line has acquired a classical reputation in the United States, and some particulars of it may be appropriate. It abounded in inclined planes, being in fact more analogous to a canal than a railroad, the planes taking the place of locks. In the spring of that season Mr. Roberts surveyed and located eight of the ten inclined planes, and afterwards superintended their construction, namely, Nos. 3, 4 and 5 on the western, and 6, 7, 8, 9 and 10 on the eastern slope of the Allegheny Mountain.

The inclination of these planes varied from about 8 to $10\frac{1}{4}$ per cent., except No. 9, which was $7\frac{1}{4}$ per cent. The longest, No. 8, being 3,116 feet (including a very short curve at the top, and a curve 200 feet long at the bottom). It had a total rise of 308 feet, the straight portion having a rise of $10\frac{1}{4}$ feet per 100, or an angle of $5^{\circ} 51' 9''$. The old Philadelphia and Pittsburg turnpike, which crossed the mountain, in sight and close by, had upon it grades of six degrees, and he made it a point, in establishing the inclination of the steepest plane on the railroad, that it should be flatter than the turnpike grade, and the fact was stated in the published reports following, for the information of the Legislature and the public. At that day there was a dread in the public mind in regard to inclined planes.

In 1832, in company with Chief Engineer Welch, he rode across the country on horseback from the Allegheny Mountain, and visited the inclined planes on the Morris Canal, in New Jersey, and those on the Carbondale and Honesdale Railroad in North-eastern Pennsylvania, both being then new, and made notes and drawings to aid in the studies of the details of our mountain inclines. Mr. Archibald was then chief engineer and manager of the Carbondale and Honesdale Railroad, upon which the inclined planes, with stationary engines at the head, had recently been put in operation.

Several plans were proposed for working the planes; the one adopted combined a double-track railroad and an endless rope.

The machinery which worked the inclined planes was simple. An endless rope of from 3 to $3\frac{1}{2}$ inches in diameter (for different planes) passed around a large horizontal, double-grooved, fixed wheel at the head of the plane, and thence, supported on numerous sheaves set in the middle of the tracks, to the foot, and around a movable, smaller horizontal grooved wheel below the foot of the plane. The lower wheel was attached to the carriage so

that when necessary, the slack of the rope, from stretching, was readily taken up. The stationary engines had double cylinders, of sizes proportioned to the particular plane. There were two systems of brakes for restraining the velocity of the rope and stopping the attached cars at pleasure; one, the ordinary iron-band friction brake; the other, a water cylinder, having a regulating valve, which, when partly closed, checked the speed in proportion to the space left open for the water to rush through, which, when entirely closed, stopped all motion. The engines were high pressure, and were built at Pittsburg and Blairsville. The ropes first used were hempen, though some grass ropes were put on during the year which answered tolerably well. The freight cars were all four-wheeled, weighing from 3 to $3\frac{1}{2}$ net tons each. The passenger cars first used were of the primitive formation, designed and put upon the road by Mr. Lot Dixon, one of the assistant engineers. They seated comfortably twenty-five persons inside, and, like a modern street car, accommodated an indefinite number outside. Frequently they "put the passenger cars through" over the thirty-seven miles, including the passage of the ten inclined planes, in about five hours, and sometimes, under the most favourable circumstances, in four hours. Upon one occasion, late in the season, the business of the road, at Plane No. 10, when the stationary engine was out of order, was carried on by means of one of William Norris's locomotives, which weighed about 12 tons, by running it empty up the plane, and then attaching it to the endless rope on the descending track, putting on steam, and thus pulling up a train on the ascending track, then detaching the locomotive at the foot of the plane, and again running it up. The same or a similar locomotive was run, by its own steam, up all the planes, including the steepest on the road, namely, $10\frac{1}{4}$ feet per 100 (541 feet per mile) for 3,100 feet of length, the total rise being 308 feet. The inclination of Plane No. 10 was $8\frac{1}{2}$ feet per 100, or 436 feet per mile, its length a little less than half a mile (2,205 feet). At the time the locomotive was run up the grade of 541 feet per mile, the opinion was that for an engine of that construction (with two drivers), $10\frac{1}{4}$ feet per 100 was near the limit at which it could be run up by only its own adhesion. There was a general impression among English engineers, assented to readily by the still less experienced American brethren, that locomotives could do very little work on grades above 30 feet per mile. There were then inclines of only 50 feet per mile in England worked with ropes and stationary machinery.

In 1835, in his twenty-sixth year, Mr. Roberts received his first appointment as chief engineer, being called to fill that position on the Harrisburg and Lancaster Railroad. In 1836 he accepted the chief engineership of the Cumberland Valley Railroad, which he held during that year and a part of 1837. During this time he planned and built the first combined railway and common road bridge, which crossed the Susquehanna River at Harrisburg. For the twenty years, from 1837 to 1857, Mr. Roberts' career was one of almost unexampled variety. He was successively chief engineer on the Monongahela River improvements, the Pennsylvania State Canal construction works, the Erie Canal, and the Ohio River improvements (1837-1841). In 1841-42 contractor on the Welland Canal (Canada) enlargement. In 1843-44 chief engineer for the Erie Canal Company, and from 1845 to 1847 chief engineer and trustees' agent for the Sandy and Beaver Canal Company, of Ohio. In 1848 appointed by the legislature of Pennsylvania to make a survey to avoid, if possible, the Schuylkill (Philadelphia) inclined plane. In 1849 chief engineer of the Bellefontaine and Indiana Railroad of Ohio, where he remained until 1851. From 1852 to 1854 chief engineer of the Allegheny Valley Railroad, a line running almost parallel with that which was the scene of his first exploits, consulting engineer for the Atlantic and Mississippi Railroad, contractor for the whole of the Iron Mountain Railroad of Missouri, and chairman of a commission of three appointed by the Pennsylvanian Legislature to examine and report upon routes for avoiding the inclined planes of the old Allegheny Portage Railroad, and from 1855 to 1857 contractor for the entire Keokuk, Des Moines and Minnesota Railroad, consulting engineer for the Pittsburg and Erie, and Terre Haute, Vandalia and St. Louis Railroads, and chief engineer of the Keokuk, Mt. Pleasant and Muscatine Railroad.

In December 1857 Mr. Roberts sailed for Brazil to examine the route of the Dom Pedro II. Railway with the purpose of bidding for its construction, and in the following year, as the senior member of a firm of American contractors, he concluded a formal contract in the United States with the Brazilian minister, Sr. Carvalho de Borges, for the construction of this road, and shortly after returned to Brazil and took active charge of the work. This line was regarded as the most difficult and expensive railway of the period; though since then more difficult and more costly works have been projected and carried through in Europe, and some with even bolder features have been constructed on the Pacific Coast of South America. He remained on the work until

its completion in 1864.¹ During the remainder of 1864 and a part of 1865 he visited various railways and public works in Brazil and the Platine republics, returning to the United States in the latter part of 1865.

Soon after his arrival in the United States Mr. Roberts took charge of the surveys for the Atlantic and Great Western Railroad, which he completed in April 1866. After some miscellaneous work in the West, he was appointed in 1866 by the secretary of war, Edwin M. Stanton, as United States Civil Engineer-in-charge of the Ohio River improvement.

In the summer of 1868 the health of Mr. J. B. Eads, M. Inst. C.E., became so much impaired that his physician urged the necessity of his resignation as chief engineer of the St. Louis bridge, and a complete cessation of all professional labour until it should be restored. The directory of the Bridge Company, however, refused to accept his resignation, but instructed Mr. Eads to select some other engineer to fill his place for the ensuing year. Mr. Roberts was selected for this service, and was in full charge of that important work during the ensuing twelve months. After Mr. Eads' recovery and resumption of his duties, Mr. Roberts remained, at the special request of Mr. Eads, for several months longer, as his chief assistant, with the title of "Associate Chief Engineer." The position of chief engineer of the great transcontinental line, known as the Northern Pacific Railway, was tendered to Mr. Roberts, and his acceptance of it in the fall of 1869 compelled a severance of his professional connection with the St. Louis bridge.

In 1874 the proposal of Mr. Eads to deepen one of the mouths of the Mississippi by means of jetties was the subject of a notable controversy among the engineers of the United States, a large and influential portion of them advocating the construction of a canal by which to avoid the obstructions at the mouth. This method had had the official approval of a board of engineers of the U.S. army in 1873. Congress in 1874 authorised the President of the U.S. to appoint a second commission to decide upon this important subject. It was composed of three army engineers, three civil engineers, and one engineer of the U.S. Coast Survey. Mr. Roberts was one of the civil engineers selected by Gen. Grant for this purpose, and in company with other members of the commission he visited the Amsterdam Canal, the jetties at the mouth

¹ A description of this railway will be found in the Minutes of Proceedings Inst. C.E., vol. xix., p. 240.

of the Danube, the Suez Canal, and the canal at the mouth of the Rhone, and subsequently the delta of the Mississippi. The report of this commission was made in favour of the jetty system in January 1875, and in the following March the U.S. congress accepted the proposition of Mr. Eads. In the succeeding fall, Mr. Eads selected seven distinguished engineers, each of whom had devoted much study to the subject, to form an advising board to examine and report upon the plans that he had matured for this work. This board consisted of Gen. J. G. Barnard, U.S.A., president, Col. W. Milnor Roberts, Sir Charles A. Hartley, M. Inst. C.E., Gen. B. S. Alexander, U.S.A., T. E. Sickels, Chief Engineer Union Pacific Railway, Prof. Henry Mitchell, U.S. Coast Survey, and D. Whitcomb, C.E., secretary of the board. All of these gentlemen excepting Gen. Barnard and Sir Charles Hartley had been members of the U.S. commission last mentioned. General Barnard was president of the board of 1873, but dissented from its recommendation of a canal. Gen. H. G. Wright, U.S.A., now Chief of the U.S. Engineer Corps, was president of the second U.S. commission, but dissented from its report in favour of the jetty system.

During the tour of His Majesty Don Pedro II. to the United States, he visited the jetties at the mouth of the Mississippi; and in 1877 he requested Mr. Eads to recommend an engineer competent to improve the rivers and harbours of Brazil. Mr. Roberts was then in Washington territory on the Pacific slope, locating the line of the N.P. Ry., and ten days beyond the reach of mails or telegrams. He was recommended for the position and accepted an offer of three years' employment for seventy-five thousand dollars, January 1879.

During the year 1876 he held the position of Vice-president in the American Society of Civil Engineers, and at the close of 1878 he was elected president of that society for the ensuing year.

He left New York on the 4th of January 1879, and arrived in Rio on the 27th of the same month. He was at once charged with an examination of the Port of Santos, and entered upon his new work in the following month. This task was completed in June, and on the 31st of August Mr. Roberts set out for an extended examination of the Upper Sao Francisco. He was accompanied on this survey by Professor O. A. Derby, of the National Museum, Mr. Rudolf Wieser, assistant, and by several young Brazilian engineers. This survey was the most difficult and important one upon which Mr. Roberts was engaged, the field work alone occupying a period of over six months. After a long interval had elapsed, during which time he served on a commis-

sion to report upon the new waterworks for Rio, Mr. Roberts was commissioned with the examination of various northern ports, and in two separate trips made careful surveys of the ports of Pernambuco, Fortaleza, Maranhao, Victoria, Caravellas, and several other small ports.

Very recently he was instructed to examine the Port of Rio Grande, but this work was afterwards deferred in order to have an examination made of the Rio das Velhas, province of Minas Geraes, during the season of low water. Accompanied by Professor O. A. Derby, geologist, and Mr. J. W. de Aguiar, assistant, Mr. Roberts set out on this his last journey on the 2nd of July, 1881. He was compelled to suspend his journey on the 7th at a little settlement called Soledado, where an indisposition that had been troubling him for some time developed into typhus fever. A week afterwards, on the 14th of July, he died, in his seventy-second year, and was buried in the parish cemetery of Caramandaby, near Barbarena, Minas Geraes.

In the course of an active career, extending over more than half a century, Mr. Roberts achieved a reputation that placed him at the very head of his profession in the United States, and which extended to this country, where he was widely known and esteemed. Although his capacity for hard work may be inferred from the foregoing record of his engagements, they give but a faint idea of the wonderful energy, physical and mental, which, even when he was past seventy, allowed of his regularly working twelve hours a day in the depths of a primeval forest. Allied to this passion for active enterprise was a simple-minded straightforwardness of character that endeared him to his friends more even than his brilliant professional powers. "Together with this bounty of Heaven in mind and in opportunity went a corresponding moral endowment—honour, faith, decision, firmness—the god within him called Integrity of Character, which is the glory of man. And with all fulness of spirit, who that knew him but must remember the shapely, vigorous frame he had, the manly front, the sparkling dark eye, the beaming smile! For never a kindlier heart beat in human bosom."¹

Mr. Roberts was elected a Member of this Institution on the 5th of December, 1876, and had promised to present a paper (which it was understood was being prepared at the time of his death) upon the River System of Brazil.

¹ *Engineering News*, New York, July 30, 1881.

MR. STEPHEN ROBINSON¹ was the only son of Mr. John Robinson, colliery engineer, and was born at Hepscott, near Morpeth, in the year 1794. He had not the advantage of much schooling in youth; for when only twelve years of age, the man in charge of a winding engine having died, his father withdrew him from school, temporarily as intended, to work the engine, and he never went back. In course of time, however, he began to feel the need of education, and applied himself, with such casual assistance as he could procure, and attained a high proficiency in such branches as he conceived to be necessary for the career proposed for himself. Subsequently he became professionally connected with several collieries, both in Northumberland and Durham, more especially with the extensive pit works at Old Hetton. He was an acknowledged authority on mining matters, and his services were often called into requisition for the adjustment of trade differences, and in the solution of mechanical problems. On one occasion he acted as arbitrator between the late Lord Londonderry and the South Hetton Coal Company. He was a personal friend of the late Mr. Joseph Pease, of Darlington, and was frequently consulted by him on questions of engineering import; and he was known to take a most lively and practical interest in the development of the railway system in the North. He was a friend and contemporary of George Stephenson, who worked for a time as an engineman under his father, and Mr. Stephen Robinson's memory was richly stored with recollections of the early struggles of that man of genius. On taking up his residence at Hartlepool, he was appointed lecturer on mechanics at Durham College, to which he paid weekly visits. His connection with Hartlepool dates from the year 1834. His repute as an engineer was then firmly established; and it steadily advanced, bringing him largely into intercourse with the leading members of his profession. Among his closest friends was Mr. John Buddle, one of the busiest and cleverest colliery viewers of his time. About the year 1845, Mr. Robinson was consulted by the directors of the Taff Vale Railway as to the best method of providing for the loading of coals at the Bute dock, Cardiff, which were then brought down by canal boats, and put into the ships by means of barrows wheeled along a plank; and he designed a system of mechanical appliances by which the coals were conveyed in 10-ton wagons

¹ This notice is mainly a reproduction of one contributed to the "South Durham and Cleveland Mercury," Nov. 19, 1881, by Mr. Robinson's cousin and successor, Mr. F. G. Morris.

along staithes, which wagons were lowered to the ship, and at a certain point sloped from front to back so as to allow the coals to slide into the hold. The contrivance gave complete satisfaction; and he was highly complimented, both by the directors, and some of his brother engineers, among them his old friend George Stephenson, who inspected the work. Near the same time, the late Mr. Ralph Ward-Jackson was endeavouring to procure a connection with Hartlepool for the Clarence Railway; and Mr. Robinson proposed to the directors of the Hartlepool Railway and Dock Company a branch to some point of the Clarence near Billingham. He had with much pains formulated a thoroughly practical and practicable scheme; but his Board declined the enterprise, and Mr. Jackson went on. Mr. Robinson ever manifested a keen interest in headland protection, and many years ago prepared a plan of his own. He designed the lighthouse on the Heugh promontory. The light, as may be known, is constructed on Fresnel's principle, and it was the first lighthouse in the kingdom lighted with gas. In conjunction with the late Mr. James Walker, C.E., of London, he designed the new pier at Hartlepool, which pier is now being extended on the lines sketched by him nearly thirty years ago—the plan having been set aside in 1855 when partially executed, and again resumed under authority of a special Parliamentary enactment. This was in his capacity as resident engineer to the Port and Harbour Commissioners. As engineer to the Hartlepool Dock and Railway Company he constructed the Victoria Dock, which was designed by Sir John Rennie, whose plans, however, were modified by Mr. Robinson to make them fit with the conditions found to exist. His services to the town of his adoption were many and great; and it is not surprising that his fellow-townsmen should delight to do him honour. Accordingly, in the winter of 1852, he was presented with a valuable oil painting of himself, the work of Burlinson, which was given, as the inscription says, together with a silver cake basket, in testimony of his public services, and of esteem for his private character. When the borough came under the Municipal Act in 1851, he was elected its first Mayor, and was made an alderman at the same time. In 1858–9 he was elected Mayor for two years in succession. And it is noteworthy that every poll in which he took part landed him at the head. Mr. Robinson was an active supporter of all the social institutions of the borough. During one of his mayoralties he was placed on the Commission of the Peace for the borough, and subsequently was made a county justice. For many years he acted as one of the county auditors to

Quarter Sessions. By virtue of his position as a county magistrate he sat in the meetings of the Guardians, and for many years officiated as chairman. He was also for some time a member of Smith's Charity Trust, served on the Stockton and Hartlepool Highway Board, and until his demise retained his seat as a member of the Burial Board. In politics he was a sincere Liberal, and in religion an attached member of the Established Church.

Mr. Robinson's death, which occurred on the 15th of November, 1881, resulted in some measure from infirmities induced by an accident sustained thirteen years before, and which increasing age prevented his rallying from. His funeral was of a public character, and gave occasion of the manifestations of sincere respect from all classes in Hartlepool.

Mr. Robinson was elected a Member on the 6th of February, 1844, but his constant residence in the country prevented his taking any part in the proceedings.

MR. CHARLES DAVIES was born at Welshpool, in Montgomeryshire, on the 9th February, 1818, and commenced his professional career as a Civil Engineer in 1833, on the Montgomeryshire Canal, under Mr. James Sword, with whom he served eighteen months; he was next employed on the Ordnance Survey in Wales, for six months in 1835. In 1836 he joined the Horseley Company's Ironworks in Staffordshire, and served a regular apprenticeship for five years, under Mr. Isaac Dodds, Assoc. M. Inst. C.E. While engineer for these works, and subsequently manager for the Holmes Engine and Railway Plant Works, by which means he gained a thorough knowledge in practical mechanics, and much experience in bridgework, as at this time the Horseley Company were engaged in the heaviest cast-iron bridge between Warrington and London. After leaving the Horseley Works, Mr. Davies still continued with Mr. Dodds as his draughtsman, manager, and surveyor in the making, and afterwards working of the Sheffield and Rotherham and part of the Midland Railways; he afterwards had the whole of Mr. Dodds' manufacturing business to conduct. From 1840 to 1846, Mr. Davies was employed with Messrs. John Stephenson and Co. on the Midland and other railways, as engineer and architect, and in keeping accounts; after his severance with them in 1846, he entered Mr. Thomas Brassey's office in London, as his secretary, and remained in this post for about four months, when he received an appointment as his agent, on the construction of the Bucking-

hamshire Railway, where he remained for three years, from 1847 to 1850. Mr. Davies was next engaged in partnership with his brother in Wales, in quarrying and contract operations, &c., which occupied him until 1858; he was then, on the 16th February, 1859, appointed an assistant engineer in the Great Indian Peninsula Railway, under a three years' agreement, and on arrival in India was placed in charge of a length of line to survey and construct, on contract No. 16 (Harda to Sohagpore); he remained in this capacity till September 1862, when he resigned the Company's service, and accepted an appointment as agent to Messrs. Norris and Weller, contractors, in succession to Mr. R. T. Mallet, M. Inst. C.E., in the construction of sixty miles of contract No. 17 of the said railway; he remained with Messrs. Norris and Weller till April 1864, when, owing to ill health, he was obliged to return to England, where he remained till March 1866; he then again went to India, and rejoined the Great Indian Peninsula Railway Company as secretary to the chief engineer, which post he held till July 1869, when he was placed in charge of the district between Egutpoora and Bhosawul, as officiating district engineer, and conducted the duties of that post up to May 1871. He was afterwards placed in charge of a length of ninety-two miles of the said railway (Egutpoora to Nandgaum), as Resident Engineer, and in March 1874, he left the railway company, and retired from the active duties of the profession, to the Kangra Valley, in the Punjab. He died at Dhurmsala on 30th August, 1879, aged sixty-one years, from an attack of fever and severe cold, brought on by exposure.

Mr. Davies was a man of a most genial and kind disposition, and this, united with long experience and a retentive memory for anecdote, made him an agreeable and much respected companion to his many friends. Mr. Davies was elected an Associate of the Institution of Civil Engineers on the 3rd December 1867.

MR. ROWLAND LYTTELTON ARCHER DAVIES¹ was the son of the late Ven. Rowland R. Davies, Archdeacon of Hobart, Tasmania. He was born at Longford Parsonage, on March 28, 1837, and educated at the grammar school at Longford, under the Rev. David Boyd, where, before going to Christ's College, Bishopsbourne, he gained the medal for Greek and prize for Mathematics.

¹ The substance of this memoir is derived from a notice in the *Hobart Mercury* for July 13, 1881.

When not yet sixteen he was removed from Christ's College, upon the retirement of the Warden, the Rev. S. B. Windsor; he was then at the head of the mathematical list, and second in classics, taking prizes in both, having privately prepared himself in higher branches of mathematics than the masters had required from the students, or had imagined any of them capable of acquiring. The year 1854 young Davies spent in Hobart, in the Engineer Office, under Colonel Hamilton, R.E., and Mr. Dawson, who has since taken a high position in the public works department in Sydney. Having chosen the profession of civil engineering as his future career, the archdeacon sent him to England in the following year, where he studied under distinguished members of the profession, by whom the many high testimonials furnished him testify to his talents having been appreciated. The first year he spent under the roof of Professor Tomlinson, F.R.S., with whom he studied specially his favourite pursuit of mathematics, and had the highest intellectual advantages, making acquaintance with the authors of that day in social circles with his tutor, who, in a tale published by his gifted wife, speaks of him as one who was once his pupil and whom he was then proud to call his friend. In 1859, Rowland Davies returned to his native land, full of enthusiasm for carrying out great works in his profession, bringing his diploma, which honour he was the solitary instance of having gained before the age of twenty-one, though it was not conferred till that period. No opening occurring in Tasmania at that time, he went to Victoria, where he obtained employment. Soon after happened that terrible railway accident at Richmond, when his life was spared, but he suffered from wounds on the head which seemed to dim the brilliancy of his talent. After recovering, he made efforts in different ways to work, the last as town surveyor in Christchurch, New Zealand. This was the first appointment of the kind in that place, and was a very arduous and trying one. He became nervously ill, and then resolved to give up his post and join an exploring party. They crossed the "Dividing Range;" particulars are given in Mr. Money's little book, "Knocking About in New Zealand." The hardships of this period led to the illnesses which caused eventually the termination of a life of so much promise. His love of the beautiful and appreciation of everything that was exquisite in nature and art is known to the few who were intimate. All who knew him well, and those who served him in households, and the poorer members of the community, loved him in a remarkable and tender degree. The renewed health and strength of the past few months revived all the energies of his nature, one of no

common order. The "Mining Journal" was the result, but proved too much for his impaired physical powers. The end came, upon all who knew and all who loved him, as a terrible shock.

Mr. Davies was elected an Associate on the 1st March, 1859. He at one time endeavoured to establish a local Institute of Engineers and Surveyors at Hobart, and also a technical school, but the community was too small to support them.

MR. HENRY HEATHER BIGG was born in Dean Street, Southwark, on the 23rd of July, 1826.

His father was possessed, through his wife, of considerable property, which he had invested, partly in a brewery at Cheltenham, and partly in a building scheme in that town, in conjunction with two gentlemen as partners. One of these partners, however, speculated without the cognisance of the others, and was very speedily involved for an amount far beyond his power of recoupment, and as a result in those days of unlimited liability, Mr. Bigg's father was ruined, and came to London with what little he could collect to start earning a livelihood as best he could. There he made the acquaintance of Mr. Sheldrake, a surgical instrument maker of that time, resident in Leicester Square, and ultimately purchased a share in his business, and in this way his son, Mr. Henry Heather Bigg, succeeded to the pursuit which he afterwards made so successful.

At the age of fourteen young Bigg left school to learn the practical details of his future business. In these he speedily became proficient and, at seventeen, was attending the different hospitals with which his father held the contracts for orthopædic appliances, and was personally supervising their adaptation to the patients.

Here it was that his quickness and aptness of perception attracted the attention of one of the staff of St. George's Hospital, who very generously offered to send him to Cambridge, and to defray all the expenses of his stay and study there, an offer declined by his father with the cynical and old-fashioned remark that a University education would unfit him for the business for which he was intended. At St. George's, however, he attended as a student the lectures on Anatomy, Medicine, and Surgery, and, although never proceeding to the actual attainment of a medical degree, he gained an extended medical knowledge, which became the basis of much of his after work.

After some time he became his father's partner, and, in 1852, he married a daughter of Dr. Robert James Culverwell, and obtained entire possession of the business on his father's retirement.

Shortly after this the Crimean War broke out, and on the return of the wounded from the Crimea he received Her Majesty's personal command to scheme the best substitutes for the lost limbs of many of the soldiers, a task which he so satisfactorily accomplished as to draw considerable encomiums from the press of the period, both general and medical. The result of his efforts in this direction were, in 1855, embodied in a book which detailed the principles of the construction and application of artificial limbs. The success of this volume was so marked and so encouraging that he immediately commenced another, which was to appear in parts, and was to describe in sequence the various orthopædic appliances best suited to the cure of the deformities of the human body. The first portion, devoted to the lower limbs, appeared in 1858, and served to securely establish the reputation he had already gained of being the first authority on the construction of such apparatus. The next portion, entitled "Localised Movements," came out in 1859; it was devoted to the gymnastic treatment of deformities, which just then had been introduced from the Continent, and was attracting much medical attention. In it the author recounted his experiences after having visited all the important continental gymnastic establishments, and having, on his return to London, built a gymnasium in which, for four years, the efficacy of mechanical gymnastics were carefully tested by him. In 1862 the final portion of the work appeared, completing his original project, and including the mechanical treatment of the spine and the upper limbs.

He had now reached a climacteric, and one which is recognisable in the lives of many successful men. They pass a large portion of their career in learning and in reaching the full power of knowledge expressed from their past experiences; and then they enjoy a term more or less lengthened, during which they utilize these experiences and this knowledge. He had passed through the first stage, and had gathered in his work an extended experience. He had fully considered and written on, one after another, all the subjects embraced in mechanical therapeutics. He had looked at it in its mechanical phase, he had looked at it in its medical phase, and he had found that whilst most surgeons understood but the rudiments of mechanics, so most surgical mechanics had but the crudest ideas on the principles of surgery and medicine. He saw that by the study of the two sciences of medicine and mechanics

in one person, a field of research would be opened, which had been almost unworked since the time of Hippocrates, and that, indeed, by the recognition of such a conjunction, a new scientific calling, which he designated "Orthopraxy," would probably arise. As surgery had in the past become gradually dissociated from the barbers' trade to rise to a science, as dentistry quite recently had passed almost from the condition of a handicraft to its present status, so he believed that in the future orthopraxy would constitute a scientific and honourable profession; and, as far as he had the power, he endeavoured to lay down the lines of this new development. Further, he determined to practically test its working, and to see if what he considered was a want would be generally recognised as such. Giving up the cramped office in which he had previously had his work transacted, he moved into a private house in the heart of a medical neighbourhood, and shaking himself free from the trammels of a business dependent largely on hospital and other contracts, he started the independent practice of mechanical therapeutics. He produced at the same time, 1865, his work entitled "Orthopraxy," which comprised, in an extended form, all the subjects on which he had previously written, as well as much fresh matter, a book which, it is believed, was the first comprehensive epitome of surgical mechanics in the English language.

And the immediate result of this venture fully justified the anticipations he had been led to form, notwithstanding the difficulties which lay in the way. For there were difficulties, of which not the least was the fact that, having failed to qualify himself as a medical man in his younger days, his proceedings were viewed askance by a large section of the medical profession, who believed that he was trenching unfairly on ground which could not justly be his, and which, if clearly defined by the sharp line of law, was none the less hedged in by the more dubious and sensitive one of traditional right and etiquette. This feeling he speedily overcame by strict adherence to set lines of conduct, and the weight of his opinions on the mechanical points in surgery came to be recognised by the leaders of the medical profession, who sent their patients to him with full confidence in his discretion and power to treat them. And so he rapidly rose into a practice which was very large, and which he enjoyed with unintermittent success till the time of his death. His literary work, subsequent to the publication of "Orthopraxy," was confined almost entirely to producing fresh and enlarged editions of that and his previous books.

His inventive talent was great, and he enjoyed a faculty of rapidly and correctly coming to conclusions, without apparently intermediate reasoning nor the knowledge of how he arrived at them. He improved on nearly all the recognised orthopædic appliances in vogue in his earlier life, and invented many new ones. Prothetic mechanisms were also brought by him to great perfection, as may be evidenced by the case of a woman at present living, who was a native of Dundee, there undergoing the quadruple amputation of both legs and arms, and was restored by him, through the substitutes he schemed, to perfect power of locomotion, and to the capability of writing and gaining her livelihood. He had the honour of successfully attending several royal personages, notably the Princess of Wales, when Her Royal Highness was suffering from an injury to her knee.

In temperament Mr. Bigg was energetic and enthusiastic. His manner was winning and courteous with women, and characterised by a geniality which rendered him popular with men. It is sad that, just as he was about to retire and enjoy the well-earned repose to which his labour and busy life had entitled him, he should have been stricken with a malady inevitably culminating in an operation under which he sank on the 30th of April, 1881, in the fifty-fifth year of his age.

He was elected an Associate of the Institution on the 4th of March, 1862.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS
AND PERIODICALS.*Periodical Movements of the Ground as indicated by Spirit-levels.*

By P. PLANTAMOUR.

(Archives des Sciences Physiques et Naturelles, Geneva, vol. vi., 1881, p. 601.)

The details of a third year's investigations,¹ viz., to the 30th of September, 1881, are here given, the Author having corrected on the 4th of October, 1880, the 7° error that had existed since 1878 in the orientation of his spirit-levels.

East end.—The depression of the level placed east and west during the winter of 1880-81 has not been so extraordinary as in the preceding one, and, generally, the curve is analogous to that drawn for 1878-79. The greatest depression ($-112\cdot66$ seconds) occurred on the 26th of January, 1881, and the highest elevation ($-91\cdot18$ seconds) on the 15th of July, while the reading at the end of the year was $16\cdot81$ seconds below that on the 1st of October, 1880. The most striking differences between the curve for this year and those for the two previous years are:—

1st. The maximum elevation of the east end took place four days before that of the temperature, instead of, as previously, considerably after it.

2nd. This end sensibly fell after attaining its maximum, although the temperature increased, and rose again from the middle of August to the end of September, though there was a marked fall of temperature. This re-rising during September has not been observed before. The greatest depression in the first and third years occurred from two to three days after the lowest temperature reading, while in December 1879 and January 1880 (two epochs of very low temperature), it took place fifteen and seven days respectively after it. All this points to the conclusion that these ground movements are caused by some other, as yet unknown, agency than temperature.

South end.—In the level placed in the meridian the amplitude of the oscillation has been more than double that of the two previous years. The greatest depression of the south end ($-9\cdot83$ seconds)

¹ Vide Minutes of Proceedings Inst. C.E., vol. liv., p. 286; vol. lx., p. 412; vol. lxiv., p. 843.

was simultaneous with that of the east end, or three days later than the minimum temperature reading. The maximum elevation (+0.37 second) occurred on the 24th of July, five days after the maximum temperature, while in the two previous years it took place nearly four months before it. The south end was 1.32 second higher at the end of this year than at its beginning, and anomalies are again presented, which prove that the ground movement in this direction also is not caused solely by variations of temperature.

As regards the part that capillarity and the molecules of the glass may play in these indications, the Author shows that this must be exceedingly small, since the bubble is nearly always kept in the centre of its run, while the temperature in the cave is almost constant for days together, its greatest range in the year being under 18° Fahrenheit. Mr. Antoine d'Abbadie, during thirty years' investigations, has observed at times the bubbles of two spirit-levels—placed side by side on the same stone—work in opposite directions. He also erected at Abbadia (in 1852) an apparatus he called "Nadirane" for observing changes in the position of the vertical, the reality of which he thereby proved. The curves he traced for 1879-1880 bear a certain analogy to those of the Author's, the differences noticed being possibly due to the proximity of the sea at Abbadia.

The Author meanwhile suggests that the anomalies presented by these ground movements are due to a slight undulation continually going on in the earth's surface, whose direction and amplitude varies in each locality according to the geological nature of the district and the forces brought into action. He forwards a letter from Colonel Orff on this subject, and proposes to compare on another occasion the results arrived at with his own.

Colonel C. von Orff, in a letter addressed to Mr. Plantamour "Sur les Mouvements du Sol," says he experimented with three spirit-levels in the cave of the Bogenhausen Observatory, distant 2 to 2½ miles from Munich. Observations were taken at 7 A.M. and 3 P.M. daily, and extended over sixteen months, from the 10th of July, 1880, to the 27th of November, 1881. The levels were all placed from 2½ to 3½ feet from the south wall of the Observatory on stone slabs supported on little pillars standing 1½ to 2½ feet above the pavement. Nos. 3 and 1 were placed in the meridian, while No. 2 was in the direction west-east, and compared with the level of the meridian circle from the 17th of October, 1880.

The results are anomalous. No. 3 level, although giving analogous readings from the 10th of July to the 27th of November both years, did not stand on the 10th of July, 1881, in the same position as on the 10th of July, 1880, while it totally differed from No. 1, which showed no periodic movement at all. No. 2, though fairly agreeing with the level of the meridian circle from the 17th of October, 1880, to the 10th of July, 1881, totally differed from it afterwards.

Four causes may be adduced for these anomalies:—

1st. Changes in the position of the vertical at the place of observation.

2nd. Changes of temperature, and their effect on the pillars and on the layers of earth beneath the levels.

3rd. Rise and fall of these layers for points very close to each other.

4th. Irregularities in the level readings, due to method of fixing the level tube and to effects of capillarity.

The first cause Colonel Orff regards as inapplicable to the observations at Sécheron or Bogenhausen, because the changes of inclination there noticed amount to twenty times those of the variation of the vertical. The second, third, and fourth he considers all influence somewhat the bubble displacements, though the effect of the second cause cannot be rightly appreciated, owing to the different thermic conditions of the strata of earth below the cave and the district surrounding it. Colonel Orff has made a fourth level, which he proposes placing alongside No. 1 level.

E. H. C.

NOTE.—A remarkable feature in Col. Orff's investigations is that the oscillations of the levels in the meridian are double those observed in the direction west-east.—E. H. C.

The Prussian Base Measured at Göttingen in August 1880.

By Dr. W. JORDAN.

(*Zeitschrift für Vermessungswesen*, vol. x., 1881, p. 377.)

This base was measured by 1st Lieutenant Schreiber (in company with the Author) by Bessel's apparatus, which consists of four compound bars of iron and zinc enclosed in wooden cases. These cases had double walls, their inner space being filled with water for the purpose of checking the temperature of the bars during use; they were covered with white sheeting as a protection against the sun. The intervals between the bars, as also the distance between their free extremities, was measured by glass wedges, but a microscopic reading of the contacts was also occasionally made.

The base-line was 5,192·8 metres (5,676·79 yards) long, with a tolerably level section for two-thirds of its length, but with a rise of 101½ feet for the remaining (southern) portion. It was laid out in 33 sections by 32 intermediate fixed points, of which Nos. 11 and 22 were marked with equal care as the ends of the base itself. This large number of "fixed" points is the distinguishing feature of this base measurement, and ensured to it very great accuracy. Each bar was laid in position by a theodolite, the end of the bar being fitted with a specially designed sliding sight for intersection by the cross-hairs. The ends of the base, as well as all its intermediate points, were twice plumbed up by two theodolites placed

on either side of the point. When any part N of, say, No. 4 bar was vertically above a fixed point, a specially divided bar was substituted for the ordinary one, after the latter had been laid, and while bars III. and I. were still in position, and the fixed point plumbed up to N by two theodolites, each about 13 feet from it. The Author recommends not to find N directly, but by calculation after first approximating to it. It should be mentioned that special lenses are prefixed to the object-glasses during this operation, to avoid difficulties in focussing at such short distances, care being taken that the collimation axis of the telescopes is not thereby disturbed. The point where work was stopped at night or at midday was found by suspending a thread over the end of the bar, and plumbing it downwards by theodolite observation upon a peg in the ground.

The thirty-four plumbings in the base measurement are lineally correct to $\frac{1}{10}$ millimetre; besides, any error therefrom is not carried forward in the work.

This base was measured—after three days' practice—the first time in three whole and two half days, and the second in two and a half days. The greatest measurement in one day was 2,043·6 metres (2,232 yards), a rate never attained before. On smooth ground all the four bars were laid in four and a half minutes, or, taking all pauses into account, in five minutes. By this rapidity all the little unavoidable changes through temperature, shaking, &c., were much reduced.

Exhaustive experiments showed that the wedges were read by eye to within $\pm \frac{1}{200}$ millimetre, and by the microscope to $\frac{1}{1,300}$ millimetre. Two successive bar intervals were always read simultaneously. In Bessel's apparatus the temperature of the bars is not directly observed, although the relation between the difference of expansion k of the zinc and iron rod, and the thermometric reading R is expressed by the equation

$$R = 46\cdot712^\circ - 21\cdot983 k,$$

where k is measured in Paris lines. The Author, however, by comparing the readings of the thermometers in the wooden cases with the temperature of the bars as calculated by the above equation, found that the latter was more correct when

$$R = 51\cdot60^\circ - 21\cdot983 k.$$

He also found that the differences between the observed and calculated values were always small, and attributes this fact to the cases being protected against solar radiation. The difference in temperature between the iron and zinc parts of the bar is hardly 1° .

The Paper concludes by very detailed calculations to show that the mean error imposed on the long diagonal in the base triangulation (a line eleven times longer than the base itself) only amounts to $\pm 2\frac{1}{2}$ millionths of its length, or about $5\frac{1}{2}$ inches.

E. H. C.

The New Survey of Berlin. By Dr. W. JORDAN.

(Zeitschrift für Vermessungswesen, vol. x., 1881, part. i., p. 11.)

The ordinance of July 1875, respecting the laying-out of streets and squares in Berlin, compelled the municipality to undertake this survey in 1876. The base selected was the side "Marienthurm-Rauenberg," its length being adopted from the Prussian trigonometrical survey. On this base seven triangles were built up, the observations of their twenty-one angles showing a mean error of ± 3.03 seconds. A 10 $\frac{1}{2}$ -inch theodolite, with Vernier reading to 10 seconds, was used in this primary triangulation, smaller instruments being employed at points of less importance. At 1st, 2nd, 3rd, and 4th-class stations rounds of angles were taken at every 12° , 24° , 36° , and 72° of arc respectively. The distribution of stations in May 1879 was as follows, viz.:

First-class stations	.	.	.	.	.	.	7
Second "	"	"	.	.	.	.	82
Third "	"	"	.	.	.	.	117
Fourth "	"	"	.	.	.	.	54
							<hr/> 210 <hr/>

all lying within the city on an area of about 20 square kilometres.

The greatest care was taken in marking trigonometrical points, and in giving distinctive signals, according to the relative importance of the station.

The protraction of the work was based on the method of co-ordinates, the meridian being taken through "Rathhausthurm," and, as Rauenberg-Marienthurm were also stations in the Prussian triangulation, a comparison of the azimuths of the line joining them showed that the azimuth obtained from the co-ordinate method was only about one-third second greater than that given by the land survey. The subjoined Table shows the accuracy obtained in fixing stations up to May 1879:

Class.	Number of Rays.	Average Length of the Rays.	Average Error in Direction.	Mean Error of the Abcissæ and Ordinates of the Adjusted Point.
II.	23	Kilometres. 3.4	Seconds. ± 3.5	Millimetres. ± 17
III.	9	1.5	5.2	15
IV.	5	0.4	6.7	8

The polygon sides run along the most sheltered parts of the streets, and where practicable along the borders of the footpaths;

they were twice measured, the mean length being used for computing the co-ordinates.

20-metre steel tapes with handles were first used, but since 1877 5-metre poles exclusively, as experiments proved that the accuracy of the measurements was thereby increased nearly one-third.

Two criticisms occur to the Author: 1st. Is a long straight line in a crowded city more accurately measured than three or four broken ones whose inclinations to each other can be traversed, and the co-ordinates of the points used directly for the detail survey? 2nd. Is it not possible by more extensive polygon measurements to considerably reduce the number of III. and IV. class stations? This latter question he considers satisfactorily answered, in this case, by the small error of ± 8 millimetres ($\frac{5}{16}$ inch) in the co-ordinates of IV. class points.

For the detail survey the city was divided into fifteen sections, and each section into blocks; the former were bounded by the limits of the principal built-over areas. Two sets of plans have been drawn, the first on a scale of $\frac{1}{250}$, the second on a scale of $\frac{1}{1000}$; each sheet is $31\frac{1}{2}$ inches long by $23\frac{1}{2}$ inches wide. The plans are completed in three stages, viz., line-plotting, detail-drawing, and ornamenting. The areas of each parcel are computed by two different men with the polar planimeter, and must agree within the following limits:—

Areas.	Difference allowed.
Hectare.	Planimeter.
0 to 0·02	0·5
0·02 „ 0·05	1·0
0·05 „ 0·10	1·5
0·10 „ 0·20	2·0
0·20 „ 1·00	0·1 per cent. of the area.
1·00	0·05 „ „

As far as the computations had been closed their agreements had been wonderfully close. The levellings executed for this survey are very extensive, as in a length of 200 kilometres (in May 1879) 1,646 heights had been fixed on an area of 1,530 hectares; 10-inch levels were used, the staves being generally held at distances of 50 metres (164 feet). The mean closing errors on twenty-four principal lines are $\pm 2\cdot9$ millimetres, and on seventy-two secondary lines $\pm 3\cdot9$ millimetres per kilometre. The levellings cost 8,743 marks, *i.e.* 43 marks per kilometre, or about 5 marks to each height fixed.

The $\frac{1}{250}$ plans are not yet published, but the $\frac{1}{1000}$ are being engraved, and satisfy every technical requirement. All shading is omitted, and writing reduced to a minimum, in order that future improvements may be inserted.

E. H. C.

Staff for Underground Levelling. By M. SCHMIDT.

(Zeitschrift für Vermessungswesen, vol. ix., 1880, p. 475.)

The rather clumsy contrivances used in the St. Gothard tunnel induced the Author to describe a staff specially made by him in 1877 for levelling in mines. It consists of two wooden poles, each $1\frac{1}{2}$ metre (5 feet) long, the front one only being graduated, while the second acts as a pedestal; they are joined together by two clamps and screws in such a way as to give the graduated pole a free play of 1.2 metre (4 feet) on the pedestal. The former is backed with an iron plate drilled at every decimeter of its scale with small holes, into which a steel pin on the pedestal works self-actingly with a spring, whenever the scale-pole is drawn in or out; the length of the staff can thus be increased up to 2.7 metres (8 feet 10 inches). A pointer is also attached to the pedestal at a height of 1.4 metre (4 feet 7 inches) of the scale, when the graduated staff is pushed home; when this staff is drawn out, the reading on the graduated staff, less the difference between its foot and the pointer, added to the constant (1.4 metre), denotes the line of sight above the foot of the pole.

For illuminating the scale, a portable reflector lamp is attached to the side of the pole, which can be raised or lowered at will, the reflector being arranged so that, while as much light as possible falls upon the scale, the flame itself is kept out of view. A stearin taper is used with this lamp, and all illumination of the wires is thus dispensed with. The verticality of the staff is shown by a box-level, attached to the pedestal and capable of being fixed at any height on it. In stony, rough, or soft ground a cast-iron shoe with a semicircular steel head is placed under the levelling staff. The cost of this staff with lamps, &c., complete is about 60 marks (£3).

E. H. C.

On the Constants in Gordon's Formula for the Strength of Columns. By Prof. MANSFIELD MERRIMAN.

(Journal of the Franklin Institute, vol. cxiii., 1882, p. 58.)

Gordon's formula for the strength of columns is,

$$\frac{P}{A} = \frac{m}{1 + n \frac{l^2}{r^2}}$$

in which P denotes the breaking load, A the sectional area of the column, l its length, r the least radius of gyration of the cross-section, and m and n are constants, depending on the material and

the arrangement of ends of the column. The Author examines the signification of the constants m and n in the following manner.

In consequence of the bending, the compressive stress on the concave side becomes greater, and that on the convex side less, than the average stress $\frac{P}{A}$.

Let S represent the greatest unit stress, and F that part due to flexure ;

Then
$$S = \frac{P}{A} + F.$$

Provided the elastic limit be not exceeded,

$$M = \frac{F L}{c}, \text{ or } F = \frac{M c}{L},$$

where L is the least moment of inertia of the cross-section, c the distance from the concave side to the neutral axis, and M the bending moment of the external forces.

But in the case of the column $M = P \Delta$, where Δ is the maximum sidewise deflection, and $L = A r^2$. Hence

$$S = \frac{P}{A} \left(1 + \frac{\Delta c}{r^2} \right),$$

or
$$\frac{P}{A} = \frac{S}{1 + \frac{\Delta c}{r^2}}.$$

The theory of elastic flexure gives for a beam supported freely at both ends and loaded in the middle,

$$\Delta = \frac{F l^2}{12 E c},$$

where E is the modulus of elasticity of the material.

Therefore
$$\Delta c = \frac{F l^2}{12 E} = \left(S - \frac{P}{A} \right) \frac{l^2}{12 E},$$

and by substitution,

$$\frac{P}{A} = \frac{S}{1 + \left(S - \frac{P}{A} \right) \frac{l^2}{12 E r^2}} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (a)$$

for round or hinged-ended columns. The formulas for columns with two fixed, or one fixed and one free end, are similar, only having 24 and 17 respectively in place of 12.

It thus appears that m in Gordon's formula signifies the greatest

unit compressive strain due to the stress P , provided the elastic limit be not exceeded. It is also evident that n is not a constant, as it varies with $\frac{P}{A}$, which, by experiment, is a function of l .

There are no means at present of determining the values of m and n beyond the elastic limit. Usually Gordon's formula is applied to rupture, and m taken to be the ultimate unit compressive strength; yet it is well known that, for instance, for wrought iron, the usual value, $m = 36,000$ lbs. per square inch, is much less than the ultimate strength. And it is also known that the formula fails for columns longer than 15 diameters. It hence appears that Gordon's formula must not be regarded as at all representing the actual laws connected with the rupture of columns.

Formula (a) appears unsatisfactory from the presence of $\frac{P}{A}$ on both sides of the equation. Solving for $\frac{P}{A}$ the Author observes, with surprise, that

$$\frac{P}{A} = 12 E \frac{r^2}{l^2},$$

which is identical, except in the constant (which should be π^2), with Euler's formula for the elastic resistance of round-ended columns.

W. P.

On Weyrauch's¹ Formulas for the Strength of Materials.

By H. TRESCA.

(Résumé de la Société des Ingénieurs Civils, Paris, 1881, pp. 228, et seq.)

The question was primarily whether the known results of experiments up to the present time, considered together, were more correctly represented by the formulas used in France or by those proposed by recent German writers. This question was much simplified by recognition of one main point of difference in the practice of the two countries. It was the custom in France, in all experiments on the strength of materials, to determine not only the breaking strength, but also the limit of elasticity and the elongations which corresponded to those two critical conditions; and the limits of working stress were based upon the limit of elasticity. In Germany, on the contrary, the recent tendency had been to fix working stresses with regard to the breaking strength of the

¹ The Paper of Dr. Weyrauch, referred to in this and the succeeding abstracts will be found in the Minutes of Proceedings, Inst. C.E., vol. lxiii., p. 275.

material. Factors of safety, regulated by experience, were used by both parties.

It would seem that the limit of elasticity was the more rational basis for calculation, since it was more nearly allied to the actual working conditions of the material. Little difference, however, existed between the limits of working stress in common use, whatever the standard of reference. It would suffice for the purpose of discussion to examine that part of Dr. Weyrauch's Paper which related to extension and compression alone. His method depended solely upon the breaking strength of the material, and ignored entirely the limit of elasticity. It did not seem reasonable, however, to consider one alone of the different properties of the material, whether that one was the breaking strength or the limit of elasticity. A close connection existed between both those elements of the question, and it remained to be seen whether the German formulas gave due weight to that consideration.

In Weyrauch's notation, a represented the intensity, or amount per unit area of section, of the "ultimate working strength," that was the breaking strength of the material under any given conditions, x, y, z representing the circumstances in which the material worked, of which conditions a was a function; so that

$$a = f(x, y, z).$$

a was here the principal variable; while in France the breaking strength was usually considered constant, at least for definite varieties of material. t represented the intensity of breaking strength under statical load, or steady load applied once for all, and was called the "statical breaking strength"; u was called the "primitive strength," and was the greatest intensity of stress not producing rupture when indefinitely alternated with complete release from stress; and s , called "vibration-strength," was the greatest intensity of the stress not producing rupture when repeated in opposite senses alternately.

The most important point in Dr. Weyrauch's Paper was the distinction between resistance to rupture by statical and repeated loading. Wöhler's experiments had shown u to be much less than t , but it was not so fully proved that a difference (similar in degree) existed between s and u . It was reasonable, however, to believe that if the effect of intermittent stress was greater than that of permanent stress, that of alternation of opposite stresses would be greater still. On the basis of the three coefficients, t, u, s , were founded those new formulas of resistance which had been used in Germany since Wöhler's experiments.

The Author repeats at length the reasoning given in Dr. Weyrauch's Paper, by which Launhardt's and Weyrauch's formulas had been arrived at,¹ and goes on to remark that the series of equations which led to Launhardt's formula, relating to repetition of stress in one sense only, might cause it to be thought rational, although

¹ *Vide supra.*

really empirical. The close correspondence between values given by it and certain experimental results of Wöhler accounted for its general use in Germany. But Weyrauch's formula still lacked confirmation by experiment. After a brief reference to Weyrauch's ingenious application of the formulas devised for simple longitudinal stress to long pillars liable to flexure, it is urged that the ideas on which the formulas in question were founded must be recognised as of great novelty and of real practical interest, and might be regarded as a first step towards a better comprehension in the future of the influence of repetition and alternation of stress on the working strength of materials. As yet they could not be said to be fully established, and being empirical in their character could only be judged by a comparison of their results with those sanctioned by experience. A typical example might be usefully quoted. Required the limiting intensity of stress to be adopted in the case of a bridge girder, for which the ratio of dead to total load was 1 to 3.5. The formula gave for answer 800 kilograms per square centimetre, and that was precisely the value which would have been fixed by practical judgment alone without calculation.

Wöhler's experiments were valuable in directing attention to the changes which might occur in the constitution of materials, but they did not conclusively show that breaking strength was a safer basis for limits of working stress than the limit of elasticity. Experience with wrought-iron axles showed that after being successively twisted and untwisted a great many times a fibrous structure was developed which was not at first visible. The facets seen, when fractures thus produced were microscopically examined, were apparently caused by the rubbing together of the ends of the fibres previously broken in detail. From Wöhler's experiments it appeared that similar, though less marked, changes in molecular arrangements occurred much before rupture. The Author admitted that the limit of elasticity was not a constant quantity; experiments on the flexure of rails, made by himself, having shown that the material remained elastic up to the stress to which it was last subjected. Nevertheless, the possibility of artificially raising the limit of elasticity was of little or no advantage to the material, since its condition then approached that of a brittle substance, and the same faith could not be placed in its permanent durability when strained. Wöhler's experiments furnished no evidence that repetition of stress below the elastic limit produced changed molecular relations in the material. Until proof of such changes was obtained the empirical formulas of Launhardt and Weyrauch could not be accepted, and the primitive limit of elasticity would remain the safest and most natural basis for the working formulas of resistance.

In conclusion, M. Tresca draws attention to the fact that, at the Conservatoire des Arts et Métiers, there are some plate-dynamometer springs which have been employed in experimental service for the last thirty years, and had in that time suffered rapidly repeated deflections, which might now be numbered by millions. The

greatest permitted deflection of these springs corresponded nearly to their elastic limit, and as yet no signs of deterioration were visible. He thought the objections raised against the limit of elasticity, as a basis for working stress, had been effectually refuted, providing that in all cases when it was so employed the primitive elastic limit suffered no alteration.

H. R.

On Weyrauch's Formulas for the Strength of Materials.

By T. SEYRIG.

(Résumé de la Société des Ingenieurs Civils, Paris, 1881, p. 250.)

Dr. Weyrauch's method of calculating dimensions, was founded upon a long series of experiments, made by Wöhler between 1858 and 1870, and repeated later by Spangenburg. Certain propositions had been deduced by the former from his own experiments, which were known collectively as Wöhler's law, and were thus expressed:—

1. A piece experiencing repeated applications of stress alternating between certain maximum and minimum values, ultimately breaks under a less intensity of stress than would produce rupture if gradually applied once.

2. The number of repetitions producing rupture increases as the maximum stress is diminished, the minimum stress to which the piece returns after each repetition remaining constant.

3. The number of repetitions producing rupture increases as the minimum stress is increased, the maximum stress remaining constant.

4. When the maximum intensity of stress does not exceed a certain limit, a , rupture does not occur, whatever the number of repetitions.

5. That limiting intensity, a , increases as the minimum stress is increased.

The Author exemplifies these propositions separately by the results of some of the experiments, and also illustrates 2 and 3 by diagrams in which the number of repetitions required for rupture are represented by ordinates whose corresponding abscissas represented the variable maximum or minimum stresses which alternated with a fixed minimum or maximum stress respectively. The experiments were made chiefly on specimens of iron and steel from the Phönix and Krupp Works, and, though not numerous or embracing much variety of material, sufficed to show a much greater similarity between the nature of iron and steel than had been hitherto supposed. Thus the ratio of s to u was, for wrought iron $\frac{7}{12}$, and for steel, $\frac{8}{15}$. It was necessary to observe that, owing to the very rapid repetition of the stress, there was no interval of repose between its successive applications. In

large metallic structures such intervals usually occurred, and it might be that the disturbed molecules then returned more completely to their primitive positions and condition of resistance—an important question that remained for future investigation. A Table is given, containing all the values of the constants a , w and s , which the experiments had furnished; and a detailed explanation of certain formulas devised by Prof. Winkler,¹ upon the basis of those values, which might suit intermediate values of a , more exactly than those of Launhardt and Weyrauch, comparing them with the latter both graphically and numerically. The Author admits the importance of the limit of elasticity, but thinks that Wöhler's experiments showed the need for fully considering the conditions under which the forces were applied to the pieces of a machine or structure; in the former, quick repetition and motion; in the latter, the varying conditions produced by the moving load. Most specifications prescribed the minimum breaking strength and corresponding elongation, but not usually the limit of elasticity. It now appeared, however, that the latter was not constant, M. Tresca² having found that it might be raised to near the limit of rupture; and under certain conditions of alternating opposite stresses, Wöhler had found rupture to occur below the primitive value of the elastic limit, which under these conditions must have been lowered. Wöhler's experiments required further confirmation, but still they sufficed to discredit those uniform limits of working stress, the use of which was at least as unfavourable to economy as to security. For if the conclusions of Launhardt, Weyrauch, and Winkler were accepted, a limiting stress, double of that hitherto adopted in France, might, in some cases, be worked to with the same margin of safety, thus giving greater economy; while in other cases two-thirds only of the usual limiting stress appeared permissible; many existing structures being therefore less secure than had been supposed.

H. R.

On Weyrauch's Formulas for the Strength of Materials.

By E. E. MARCHÉ.

(Résumé de la Société des Ingénieurs Civils, Paris, 1881, p. 261.)

Although the experiments of Wöhler had been made too carefully to permit doubt, either of their accuracy or of the truth of the law founded upon them, it was otherwise with the new formulas deduced from that law by other German writers, and they should not be accepted without investigation. The existence

¹ *Vide Minutes of Proceedings Inst. C.E.*, vol. I., p. 201.

² *Ante*, p. 329.

of the "primitive strength" u , was a direct conclusion from Wöhler's experiments, and Mr. Seyrig's diagrams¹ shewed it to be the abscissa of the vertical asymptote to the curve representing the variation in the number of repetitions of any given stress required to produce rupture, and its accurate determination, was necessarily difficult. After quoting in detail some experiments of Wöhler's on Phönix iron and Krupp steel by repeated flexure, the Author infers that, from the entire number of experiments made, two values only of u could be deduced, viz. 22 kilograms per square millimetre for wrought iron, and 37 kilograms for steel. These were, sensibly, the primitive limits of elasticity of the same materials, and it was indeed remarkable that the German experimenters should propose to supersede the limit of elasticity by a new constant, which was only the same thing under another name. That rupture necessarily followed the repeated application of stress above the limit of elasticity he thought was scarcely yet fully proved. He conceived that when rupture occurred through repetition of stress below the statical breaking strength, it was due to alteration in the molecular state of the material, produced by vibration and manifested by diminished cohesion or by displacement of the limit of elasticity. Future experiments should tell something more than the mere number of repetitions required to produce rupture. After a certain number of repetitions the limit of elasticity and breaking strength should be again determined, in order to ascertain whether and to what extent their primitive values had been altered. Wöhler's experiments showed with certainty that stress below the elastic limit may be alternated an indefinite number of times with any less stress of the same sense, or with zero, without fear of rupture or molecular alteration of the material. But the experiments on alternate tension and compression which had led to the coefficient s and Weyrauch's formula deserved serious attention, and suggested the need for diminished limits of working stress in such circumstances. He held that, for repeated stress of one sense only, it was sufficient to fix the working stress at one-third of the limit of elasticity; and that, in the case of alternations of equal stresses of opposite senses, one-third of the value found for s might be used.

The facts which had been ascertained by M. Tresca and others, relative to permanent deformation were of great importance but since they only existed when and because the elastic limit was passed, they should not be used as data for calculating the strength of materials which, by the very conditions of their employment, were required to remain elastic and not to become modified or deformed.

H. R.

¹ *Ante*, p. 332.

On Weyrauch's Formulas for the Strength of Materials.

By E. TRELAT.

(Résumé de la Société des Ingénieurs Civils, Paris, 1881, p. 264.)

The Author, believes the limit of elasticity to be a more satisfactory basis for limits of working stress than the breaking strength. The business of an engineer was to so design the different members of a structure that the greatest loads should produce no visible permanent changes of their form and dimensions. For brittle materials, such as stone, which suffered no permanent change of form before breaking, deformation was proportional to the force producing it up to rupture; and it was therefore right to fix the safe working load as a fraction of the breaking strength. For those materials which could experience permanent deformation before rupture, experiment had shown their resistance to comprise two distinct periods, in the first of which they were elastic, while in the second they suffered permanent change of form. The boundary between those two periods, in other words the primitive limit of elasticity, marked the limit of safe employment for such materials with due regard to preservation of their form and dimensions; and the safe working stress should be taken as a fraction of that primitive limit. If the limit of elasticity was artificially raised the working stress should be a smaller fraction of that new limit. Future experiment in such special cases as that of repeated alternation of stress in opposite senses, might show to what extent the primitive limit of elasticity was lowered, or perhaps that it coincided with the breaking strength under those conditions. The existence of the different limits of rupture indicated by the symbols t , u , s , did not diminish the utility of the limit of elasticity as a standard of working resistance; but showed that its character should be accurately determined and the factor of safety fixed with due regard to circumstances.

H. R.

On Weyrauch's Formulas for the Strength of Materials.

By A. BRÜLL.

(Résumé de la Société des Ingénieurs Civils, Paris, 1881, p. 286.)

Admitting the value of Wöhler's experiments, it was best to retain the primitive limit of elasticity as the standard of working resistance. It had been shown by experiment that under certain conditions neither limit of elasticity nor breaking strength preserved their primitive values. But in working practice such conditions seldom existed, and the former might then safely be held to possess a definite and constant value. Wöhler had, in many instances, broken specimens of iron and steel by alternation of

equal opposite stresses below the elastic limit; but the stress was very rapidly reapplied, though not with shock or absolute suddenness. It was well known that the minimum intensity of a suddenly applied load, required to produce a given elongation was half that of the corresponding statical stress, when the given elongation was below the elastic limit. From this it was inferred by Lippold, that the sudden application of stress below the limit of elasticity but exceeding half its value, produced some permanent set, and at each repetition of the same stress a certain amount of work was spent in producing that result; rupture following when the total work so expended attained a sufficient value. The complex methods of calculation of Dr. Weyrauch, could not replace that based on the limit of elasticity until, for different qualities of material, prolonged experiment had furnished more definite values for the new coefficients.

H. R.

On Weyrauch's Formulas for the Strength of Materials.

By H. MATTHIEU, President of the Society of Civil Engineers of Paris.

(Résumé de la Société des Ingénieurs Civils, Paris, 1881, p. 270.)

Experiments made by the Author twenty-five years ago showed that, by successive applications of stress, at first feeble and gradually increased by very small and equal increments, the breaking strength was raised above the primitive value. But when this process was commenced with an initial stress equal to half the primitive breaking strength, rupture was produced by less stress than in the first case. The limit of elasticity seemed, therefore, to vary according to the manner in which it was sought for.

While rendering full justice to the remarkable labours of the German experimenters, M. Matthieu thinks that French engineers will retain their belief in the principle of the limit of elasticity, which in France had served hitherto as the basis of the theory and the practical formulas of the strength of materials.

H. R.

The Thrust of Earthwork. By H. DE LAGRENÉ.

(Annales des Ponts et Chaussées, December 1881, p. 441.)

The Author remarks that the number of articles inserted in the "Annales" on the thrust of earthwork and on retaining walls, would seem to show that the solutions indicated have not attained the necessary degree of clearness for easy remembrance and application to practical cases. This he attempts to realise in the present note. Surcharged quay walls are treated on, but the case most often presenting itself in works of the *Ponts et Chaussées*, is

that of a simple retaining wall supporting earth with a level surface, and the results of his calculations for such cases he claims can be easily remembered. For earthworks having a slope of repose of 45° , he finds the thrust will be about $\frac{1}{3}$ of that of water; whilst with a slope of 30° it will be $\frac{1}{12}$, and with one of 20° about $\frac{1}{4}$ of the same. It is assumed that the earth is not surcharged, that its weight is 1.75 time that of water, and that it thrusts against a vertical-backed wall.¹

The Author calls attention to the important practical fact that the critical moment for many quay and dock walls is when the water subsides rapidly after a flood. To determine the slope of repose assumed by earth under such circumstances, M. Lagrené made experiments with a model, and found that with the light earth used behind the lock walls at Mentan, the slope assumed was $24^\circ 13'$, the weight of the wet earthwork being 1.86 time that of water. At St. Aubin, where the filling was gravelly, this slope was 30° , and the relative weight 1.8. At Notre Dame de la Gavenne the light earthwork slope was 35° , and relative weight 1.58. With gravel and sand mixed the slope was 30° , and weight 2.15; and with the sand of the Isle of Mouchonette the slope was $36^\circ 4'$, and the relative weight 1.534. These variations, the Author says, show that the choice of the earthwork filling behind lock and quay walls is a matter of importance.

B. B.

Description of the Teesta Suspension Bridge. By W. B. CHRISTIE.

(Professional Papers on Indian Engineering, vol. x., No. 42, p. 1; 1881, p. 81.)

This bridge is situated on the road between Darjeeling and the Thibet frontier. The works were commenced at the end of November, 1879, and completed on June 22nd, 1881, from which interval four months have to be deducted, during which time work was entirely stopped.

The span of the bridge is 300 feet, and the width of the roadway 6 feet, the difference between the flood level and the under side of the latter being 20 feet. The suspension cables are of soft steel wire (each cable having four strands), 2 inches in diameter, weighing 8 lbs. per lineal foot, the length of one strand being 465 feet, or a weight of 1.67 ton ($46\frac{1}{2}$ maunds). These are placed side by side and bound together by cast-iron saddles fixed 5 feet

¹ It may be remarked that these results are based upon what was termed in a recent Paper on the "Actual Lateral Pressure of Earthwork" (vol. lxx.), the "ordinary theory"; and that they are not corroborated by the results of actual experiment. The criticism of the Paper referred to by continental engineers would lead to the inference that the "ordinary theory" was no longer acted upon on the Continent, but the above note by an engineer-in-chief of the Ponts et Chaussées would appear to lead to an opposite conclusion.—B. B.

apart, from which depend the suspension wire-ropes of $\frac{3}{4}$ inch diameter.

The versed sine of the curve of suspension is 24 feet, and the distance between the cables at the centre of the bridge is 8 feet, gradually splaying to a width of about 15 feet at the piers, thus adding considerably to the rigidity of the platform. Assuming a wind pressure of 55 lbs. per square foot (recently recorded in Calcutta), the area exposed to the force of the wind being about 850 square feet, the consequent pressure would in that event amount to 21 tons, to assist in counteracting which a pair of guy ropes, anchored on both banks of the river (above flood level) both up and down stream, are attached to the platform at about one-third of the span.

For calculation, the chord =	.	.	.	.	.	.	.	.	.	Feet.
Width of roadway =	.	.	.	.	.	.	.	.	.	312
Versed sine =	.	.	.	.	.	.	.	.	.	6
	.	.	.	.	.	.	.	.	.	24
Dead load	.	.	.	.	.	.	.	.	.	Tons.
Live load (at 60 lbs. per square foot)	.	.	.	.	.	.	.	.	.	51.8
	.	.	.	.	.	.	.	.	.	48.2
	.	.	.	.	.	.	.	.	.	Tons.
	.	.	.	.	.	.	.	.	.	100
∴ Strain at centre	$\frac{100 \times 312}{8 \times 24} =$									162
Strain at abutment (from measurement on plan)										169
	(or $\frac{169}{8} = 21$ tons per cable).									

(Cables similar to these used have been tested by Mr. Kirkaldy up to 137 tons).

The site of the works was approached from the nearest cart-road, 18 miles distant, by a steep and narrow bridle-path. The total weight of ironwork to be conveyed over this was 50 tons. Portion of the plate ironwork (in connection with the anchorage) was sent out in pieces weighing about 17 cwt., but these it was found necessary to cut in half, their length being too great, viz., 32 feet, for conveyance over the sharp curved track. Each cable, 465 feet long, was carried by 60 coolies, who when accustomed to the work were able to make the journey of 18 miles in three days. Much difficulty and loss of time was experienced in conveying the cast-iron pier saddles, weighing $2\frac{1}{2}$ tons each, to the site of the works, and two of the four had to be omitted, they not being on the ground in sufficient time. For these very strong timber saddles of hard wood were substituted, which can be changed hereafter if necessary. The Author considers that no piece of ironwork required to be conveyed over such tracks as that in question should exceed $\frac{1}{2}$ ton in weight. The above saddles would have been cast in three separate pieces had the makers followed out their instructions. A description of the anchorages, and also of the mode of erection, which had to be effected without scaffolding, is given.

The amount of masonry in the bridge is 162,569 cub. ft., or 6,021 cub. yds.			
"	ironwork	"	50 tons.
"	woodwork	"	1,465 cub. feet.

The time occupied in the various operations is given, and also the particulars of cost, a summary of which is as follows:—

	Rupees.	£.	s.	d.
Excavation	4,990	499	0	0
Masonry	54,123	5,412	6	0
Woodwork (labour only)	1,554	155	8	0
Steel and iron	24,350	2,435	0	0
Erection	23,312	2,331	4	0
Stores and contingencies	10,679	1,067	18	0
	<hr/> 119,008	<hr/> 11,900	<hr/> 16	<hr/> 0

Cost per lineal foot of clear span £39 14s. (397 rupees).

D. G.

NOTE.—Rupee assumed as equal to 2s.

Viaduct over the River Daó on the Beira-Alta Railway, Portugal.

(Annales des Travaux Publics, 1882, p. 561.)

The railway upon which this work is situated is intended to establish a direct communication between France and Lisbon. The character of the country passed through within Portuguese territory is of a very rugged nature, necessitating the construction of numerous viaducts, generally of iron, and of which the above is one of the most important.

The viaduct comprises three openings; viz., a centre one of 246 feet, and two side ones, each of 184 feet 6 inches span. The abutments are of masonry, and the two piers of wrought-iron framing on masonry bases; the height from the surface of the ground to rail level at these being about 162 feet. The main girders (trellis) are 24 feet 7 inches deep, and 16 feet 9 inches apart from centre to centre, allowing a clear width between them of 15 feet 3 inches. The top and bottom flanges are of tee section; in the former instance composed of a vertical plate 1 foot 8 inches deep, a pair of angle-irons, and horizontal plates 1 foot 6 inches broad; the lower flange being the same, excepting that the vertical plate is 3 feet deep. The trellis bars of the web are of tee section, varying in component parts according to their position. The web-verticals are 24 feet 8 inches apart, excepting for a distance of about 61 feet 6 inches on both sides of each of the piers, where they are only 12 feet 4 inches. They are of double tee section, made up of plates 9 inches broad, connected by four angle-irons to a web of 1 foot 6 inches in depth. This web is enlarged to a gusset near the top and bottom flanges, as an attachment for the overhead bracing and cross girders respectively; these latter are 12 feet 4 inches apart and 3 feet deep. The longitudinal bearers (plate-iron) are placed directly under each rail, their distance apart, from centre to centre, being consequently 5 feet 8 inches (Portuguese gauge); their depth is 1 foot 8 inches. The bracing of the main girders also

includes, for the lower flange, horizontal diagonal 6-inch bars, intersecting at every second cross girder; and for the upper flange, overhead cross-ties at the web-verticals, formed by lattice girders 1 foot 8 inches deep, and diagonals each composed of two angle-irons. The main girders are supported on the piers and abutments, through the medium of hinged bed-plates, in which the upper plate is affixed to the under side of the girder, and rides upon a transverse bar, forming part of the lower bed-plate; these latter again, where expansion has to be allowed for, rest on rollers. The adoption of this hinged bed-plate permits only of vertical reactionary forces which must pass through the hinge-joint, or centre of support.

Each of the piers is composed of four corner piles of channel section (of plate-iron and angle-irons), the sides measuring 1 foot $7\frac{1}{2}$ inches by 1 foot 2 inches, with a batter of about $5\frac{1}{2}$ to 1, into which butt the horizontal and diagonal bracing of box section with angle-iron corners and lattice-bar sides (1 foot $3\frac{3}{4}$ inches by 1 foot 2 inches).

The ironwork of the superstructure was erected on the adjacent railway embankment, which had been made up to 1 foot $7\frac{1}{2}$ inches above the pier-top level, and thence launched across the openings into position. Owing to the available length for erection being only 328 feet the launching could not be completed at one operation, the procedure was as follows:—a pair of temporary pedestals were fixed upon each pier so as to be immediately under the main girders. On the summit of each of these pedestals was a transverse groove, on which was supported a balance-bar attached to the under side of a short box-girder, 13 feet long and 1 foot $7\frac{1}{2}$ inches deep.

This box-girder carried on its upper table, at each end, a frame (also on balance-bars) with bearings, in which were two rollers (on each frame) of 1 foot $7\frac{1}{2}$ inches diameter, the axles, 4 inches diameter, of which extended across, so as to connect with those on the frames of the second pedestal. Two of the four axles were extended, so as to be clear of the main girders under launch, which latter immediately rested upon the before-mentioned rollers, and carried at their ends toothed wheels into which geared the heads of levers: these were fitted with wooden arms of sufficient length to allow of their being worked by men from the level of the top of the main girders. The levers were tied together above, so as to ensure simultaneous action.

By means of the hinged joints the weight of the superincumbent girder, during all its varying positions while in movement, was equally distributed upon the four pairs of wheels, with a vertical resultant passing through the centre of the pedestal.

On account of the unusually large span of the centre opening, viz., 246 feet, it was considered desirable to reduce the weight to be carried by the rollers as much as possible, and therefore only as much of the cross girders and bracing were erected as would ensure the requisite rigidity; the remainder of the work being done after the superstructure was in its definite place.

With the same object, a pair of comparatively light girders, 69 feet long (intended for an opening elsewhere), were temporarily secured to the fore end of the girders under launch. The greatest pressure upon each roller was 32.3 tons, or $32.3 \times 8 = 258.4$ tons, on the first pier. The amount of flexure of the first pier at the moment before the projecting girder landed on the second pier was 1 foot $5\frac{3}{4}$ inches, or $\frac{3}{4}$ inch less than the theoretical flexure. The erection of the piers, the superstructure, and the launching of the latter into place, occupied from May 1 to July 31, 1881. The launching of the central span was effected in one day.

D. G.

*Report of the Results of an Examination made in 1880 of several Sewerage Works in Europe.*¹

By RUDOLPH HERING, Civil and Sanitary Engineer.

(Supplement No. 16, National (U.S.) Board of Health Bulletin.)

In eight large cities it appears that the average length of sewer per inhabitant contributing is 2 feet, and that the average length of sewer per acre of sewered area is 171 feet.

In Berlin, circular pipe sewers are used up to 20 inches diameter. Brick sewers are egg-shaped, the width being two-thirds of the height. The size is determined by Eytelwein's formula in the following form for metres, for egg-shaped sewers two-thirds full,

$$v = 50 \sqrt{\frac{3.023}{4.788}} r s = \text{velocity in metres per second,}$$

in which r = the mean radius,

s = the sine of the slope.

$$\text{Log. } D = 2.0803 + \frac{5 \log. r + \log. s}{2},$$

in which D is the discharge in cubic metres per second. The depth of rainfall calculated upon is $\frac{1}{4}$ inch per hour, of which $\frac{1}{4}$ is assumed to evaporate, $\frac{1}{4}$ to penetrate the ground, and the remaining $\frac{1}{4}$ to enter the sewers. The quantity of sewage estimated is 30 gallons per day for each of 324 persons per acre, one half of which is to run off in nine hours. The population is 1,118,630. The surface of the city being extremely flat and low, it is divided into twelve independent drainage districts. The sewage from each district is collected at a lowest

¹ The information relating to the London sewers is omitted in this Abstract as being well known. The same applies to several continental cities the drainage of which has been described in the Minutes of Proceedings.—Sec. IX. C.E.

point, the pumping station, and thence raised through iron mains to either of two farms, one situated to the north-east, the other to the south, of Berlin. The pumps are intended to raise besides the sewage only a first flush of rainwater; therefore numerous overflows are provided to relieve the pumps of any greater quantity. The greatest calculated dilution of sewage at the moment when the overflows begin to act is 1 to 8·186; the greatest dilution when sewers are running full, 1 to 153·2. The sewage farm on the north-east is at Falconberg, 6 miles from the centre of the city, the area of the farm being 1,830 acres; that on the south is at Osdorf, 9 miles from the centre of the city, its area being 2050 acres. A novel feature are the winter basins, into which the sewage is turned after vegetation ceases, to a depth of 2 feet, and allowed to soak away. The odour from them is very great, but there are no houses within a mile of the spot.

In Vienna pipe sewers are not used. The invert is rather flat, the radius being but little less than that of the arch. The sewers are all sufficiently large to be entered by a man. The capacity is calculated, according to Darcy and Bazin's formula, in the following form—

$$\text{Mean velocity per second} = \sqrt{\frac{\frac{\text{sect. area}}{\text{perimeter}} \times \text{sine of slope}}{A + B \frac{\text{perimeter}}{\text{sect. area}}}},$$

$$A = 0\cdot00019; \quad B = 0\cdot00013.$$

The maximum rainfall provided for is over 1 inch per hour, supposing $\frac{3}{8}$ inch to get into the sewers, and to fill them only to the springing of the arch. The gradients are, as a rule, very good; the minimum is 1 in 608.

In Hamburg brick sewers are all egg-shaped, except the intercepting-sewers, which are circular. The size is calculated by Eytelwein's formula, the basis being 1 inch of rain in twenty-four hours, of which $\frac{3}{8}$ is to flow into the sewers. This refers mainly to the intercepting-sewers. The minimum sizes of the ordinary sewers are large enough to be walked through; while, on the other hand, overflows into the Alster, or canals are provided wherever possible. The amount of sewage is calculated at 39½ gallons per head per day, one-half to flow off in nine hours. The gradient of the large sewer, 10 feet in diameter, is 1 in 3,000 for nearly 8 miles. When half full, it has a surface velocity of 1 metre per second. The rings of brickwork in the sewers have a coat of strong mortar between to make them watertight. The larger sewers, from 5 feet 6 inches to 8 feet 6 inches high, have three rings in the invert, extending above the springing; the 10 feet sewer has four complete rings; the sizes smaller than 5 feet 6 inches have two rings. Portland cement is used in the proportion of 1 of cement to 3 of sand.

In Frankfort-on-the-Main pipe sewers of 12 inches and 15 inches diameter are used. The smallest brick sewers are 2 feet 10 inches

by 1 foot 11 inches. The sizes were governed by three considerations: first, by a maximum quantity of rain to be carried off; secondly, by convenience of construction, as it was found preferable in the many streets which required tunnelling to fill the entire space by a brick sewer 2 feet 10 inches by 1 foot 11 inches, instead of by a small pipe and packing the remaining space with earth; thirdly, by the gradient, for the convenience of cleaning. The intercepting sewers are calculated to receive a rainfall of $\frac{1}{2}$ inch in twenty-four hours plus a daily amount of sewage of 36·7 gallons per person. The overflow sewers are intended to remove an amount equal to $\frac{1}{4}$ inch per hour.

The formula used is, in metres—

$$\text{Log. sine of slope} = \text{log. coeff.} + 1\cdot8 \text{ log. mean velocity} \\ - 1\cdot25 \text{ log. mean radius,}$$

$$\text{or } s = c \frac{v^{1\cdot8}}{r^{1\cdot25}}.$$

The values of the coefficient c are for—

Cast iron and earthenware	0·00018
Brick	0·00030 to 0·00025

The consideration for cleaning gave the following minimum sizes:—When the inclination is less than 1 in 500 the size is at least 4 feet 8 inches by 3 feet; between 1 in 500 and 1 in 100, the size is 3 feet by 2 feet; for more than 1 in 100 pipes 12 inches and 15 inches in diameter are the smallest sizes used. The ordinary mean velocity in the mains is about 16 inches per second. The ordinary depth of cellars is 9 feet 5 inches, and the least depth of sewers is usually 13 feet 1 inch. The average depth is calculated at 17 feet.

At Danzig there are three drainage areas, the south-east, which is a low and flat district, the north, and the south-west. Each one has a main collecting sewer, delivering the sewage at a pumping-station on an island in the river Mottlau. The two arms of this river and the Radaune are crossed by inverted siphons 27 inches and 18 inches in diameter. There is another siphon 18 inches in diameter under the moat, connecting the suburbs east of the town. From the pump an iron main 22 $\frac{1}{2}$ inches in diameter delivers the sewage at the farms in a north-easterly direction, crossing a branch of the Mottlau, the moat, and the Vistula, by inverted siphons. These are of wrought iron, and lie about 15 feet to 18 feet below the mean water level. Before the sewage enters a siphon it passes through a horizontal screen, which retains all floating matter, and then over a catch pit, where all heavier particles subside.

C. SL.

*On Sewer-Gas as a Factor in the Spread of Epidemic Diseases
and on the Direction and Force of Air-Currents in Sewers.*

Part I.—By Dr. SOYKA, of Munich.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1882, p. 33.)

The Author draws attention to the fact, that while England was the first country to introduce an improved system of sanitation, it was in Munich that the theory of the dangerous nature of sewer-gases originated; a doctrine which is receiving a considerable share of attention in Germany, the tendency being greatly to exaggerate the danger. According to this theory, the air contained in the sewers, on escaping into the streets and houses, occasions the spread of epidemic diseases. In England this doctrine is gradually taking the place of the favourite, but somewhat exploded, notion of infection by means of the water-supply. For, whereas formerly whenever any impurity in the water was detected this was at once made answerable for any outbreak of typhus¹ or cholera; so now typhus, diphtheria, and other diseases of this type, are immediately declared to be caused by some faulty drain or water-closet. It is frequently not even considered necessary to prove that there has been any actual escape of sewer-gas, and no attempt is made to trace the possibility of any contact of the patient with such gases. The convenience of making the foul gas responsible often, indeed, hinders any proper investigation from being made into other possible causes of infection. In considering the subject, all cases of sudden death or illness caused by inhaling the impure gases in sewers, latrines, and similar places, may be left out of the question, for what is now to be dealt with is not sewer poisoning, but the spread of certain diseases, either of an endemic or epidemic character, which arise in consequence of the reception into the system of an organism, which there multiplies and becomes the germ of new cases of infection. For, while it is impossible to deny that long continued exposure to impure gases may cause a feeling of illness and discomfort, it is not pretended that the foul gas in sewers can give birth to the germs of typhus, diphtheria, &c., but only that such gases serve as the medium in which these organisms are suspended and conveyed to the patient. The Author gives a Table showing the mortality from typhus, or so-called "enteric fever," in a number of English towns, before and after the completion of the sewerage; and some special Tables relating to Croydon, showing a spring and an autumn maximum in the cases of zymotic diseases. Dr. Buchanan is quoted, and blamed for contenting himself with the fact that the infected houses, in the latter case, were connected with the sewers, without making any attempt to prove that the sewer-gas escaped into the dwellings. He stated, indeed, that no smell of sewer-gas was perceptible, and

¹ The fever known as typhoid or enteric fever in England.—G. R. R.

argues from this fact that the inodorous gases were the most dangerous ones. From an examination of the facts respecting Croydon the Author concludes that there is no proof of the connection between the sewerage system and the outbreak of typhoid fever which took place there in 1875. He observes that he has devoted a large share of attention to this particular case, because it is the only one in which an epidemic of this nature has received careful scientific examination, and because it greatly supported the theory of sewer-gas infection. He states that this investigation forcibly recalls the Report of Radcliffe, on the cholera epidemic of 1866, and his theory that the spread of the infection was caused by the mains of the East London Water Company, whereas Letheby most convincingly proved that the supply-pipes of the Commercial Gas Company might with equal reason be suspected (i.e., because both companies served the infected district), and that, as a curious coincidence, the first case of cholera occurred at the gasworks. Instances of outbreaks of an epidemic character are always more or less traceable to some one similar source of infection, and for this reason the water-supply, the milk, and such-like, have been at various times accused. In a similar way Drs. Scott and Littlejohn attributed the fever-outbreak in Selkirk in 1876 to the bad drainage, and the Baden-Baden, Gibraltar, Caius College, and Dublin epidemics have all been set down to defects in the sewers. Dr. Soyka further refers to other diseases, such as erysipelas, bronchitis, and diarrhoea, which are said to have been propagated by sewer-gas.

Passing on to foreign experience, and selecting typhus as being essentially a disease whose spread is due to excrementitious matter and the emanations therefrom, the Author gives careful Tables of the health statistics of Hamburg, Dantzic, Frankfort-on-the-Main, and Munich, both before these towns were provided with a regular drainage system and after the drainage was completed; and shows by these figures that the death-rate from typhus has greatly decreased since the towns were thoroughly sewered. Taking another of the zymotic diseases, diphtheria, and considering the question whether or not it is gradually taking the place of typhus, he shows that the former is essentially communicated by direct contact, and that it is a disease infinitely more destructive in country districts than in towns, and one with which sewer-gases can therefore have but little to do. He also considers the prevalence of enteric diseases in the sewered and the unsewered portions of the same town, and shows that in every case proper drainage has largely diminished the mortality from these diseases. He gives the results of the investigations of Mayer respecting the cholera outbreak in Munich in 1873, and shows that the streets provided with sewers were much freer from illness and death than those which were undrained; the number of cases of illness being 230 per 10,000 in the undrained streets, and only 114 per 10,000 in those streets which were properly sewered. His conclusions are as follow:—

1. It has been seen, in the first place, that the facts and arguments adduced in favour of the sewer-gas theory are by no means free from suspicion, and that, on the contrary, the demonstration is faulty and incomplete.

2. It has been proved that the sanitary conditions, more particularly as respects a special class of infectious diseases, have become substantially improved in towns provided with sewers.

3. That in towns in the various districts of which different methods or systems of excrement-removal prevail the drained areas show no unfavourable prominence in regard to the presence of infectious diseases, and that, if indeed any connection is traceable between the sewers and such diseases, the influence of the drainage is a favourable one.

4. That the spread of certain infectious disorders (diphtheria), which is believed to be dependent on the state of the town as respects the sewerage, appears to depend upon entirely different conditions, and to put the whole matter briefly:—

(1). “The positive proof of a connection between sewer-gases and the spread of epidemic diseases is wanting.”

(2). “The majority of the experiments hitherto made lead us to conclude that the spread of epidemic diseases is entirely independent of sewer-gases, and that those towns, or parts of towns, provided with sewers are more favourably circumstanced, as evinced by their sanitary conditions, than the same towns before the drainage was commenced, or the districts which are still undrained.”

Part II.—By Dr. ALADÁR V. RÓZSAHEGYI, of Pesth.

The Author states that at a time when vast drainage works are being undertaken, and so many important towns are adopting, or are prepared to adopt, the water-carriage system, it is advisable that the objections to this plan of excrement-removal, which have been raised on the score of the dangers arising from sewer-gas, should be carefully and fully investigated. The theory that zymotic diseases are really due to the entry of sewer-gas into dwellings is based upon the observation that the high-lying portions of towns, and those inhabited by the wealthier classes, which are then assumed to be the higher-lying districts, are more liable to enteric diseases than the lower quarters of towns. The proofs brought forward in favour of this being that in certain affected houses the drainage was out of order, and that bad smells prevailed in the houses situated in the upper parts of towns. The reason alleged for this being, because, owing to its chemical composition, sewer-gas is specifically lighter than atmospheric air, and naturally rises to these points; moreover, certain specific observations have been recorded in which a positive pressure was found to prevail in sewers. The inference from all these facts is, that sewer-gas has a decided tendency to force itself outwards from the sewers, and consequently into houses.

From a consideration of the static and dynamic laws governing the movement of gases it may easily be argued that there are numerous factors which must be studied before any decision on this matter can be arrived at. Taking first the chemical nature of such gases, the Author shows that the balance of evidence, excluding certain misleading experiments conducted with gases evolved from cesspools and closed vessels containing faecal matters, leads to the belief that in lieu of being lighter than the atmosphere, sewer-gases, owing to the presence of rather more than the usual amount of carbonic acid, are really heavier than air.

The differences in specific gravity of the sewer-gas, due to the moisture it contains, are next dealt with, and the effects of the greater heat of the atmosphere in houses than in the sewers, and in the sewers themselves than in the soil through which they pass, are noticed. The Author shows that the flow of water in the sewer has in many cases an important bearing upon the air currents they contain. The state of the barometer also is not without a marked influence on the sewer-gases, and the force of the wind has much to do with the pressure of the air in the sewers. He points out, finally, that the currents in different parts of the same system of sewers have in many cases a conflicting action upon one another.

The Author states that he has dwelt at considerable length on these facts in order to prove that the gases in the sewers are exposed to numerous varying influences, thus rendering it very difficult to establish any general laws. He then details his own observations, which took place during the summer months, over a portion of the main sewers of Munich. He employed tobacco-smoke to indicate the general direction of the air-currents, and sulphuretted hydrogen gas, with strips of paper dipped in acetate of lead and moistened with glycerine, to show the distances traversed and the time occupied by gases in passing through the sewers.

These experiments demonstrated the fact that the general direction of the air-currents in the main sewers was downwards, i.e. in the direction of the flow of the sewage-water, and more markedly so in the deeper lying sewers, i.e. those nearest the outfall. At the soil-pipe openings into the houses the direction of the air-currents was very variable; more frequently, however, there was a draught into, rather than away from, the house. The ventilating power of the running water in the sewer appeared to the Author so important that he carried out a series of experiments with tin pipes of elliptical section and fixed at various inclinations, having water flowing through them, both as a flat or as a deep pipe (○ or O); and he gives a Table of the air-velocities in these pipes under various conditions. His conclusions are as follow:—

1. The air in sewers is influenced by a large number of factors, varying both as respects time and place, direction and force.

2. The results obtained during the summer months and when no rain fell were, that the sewer-gases rarely passed upwards in

the sewers, but, on the contrary, almost invariably downwards; but that the more frequent tendency, at the same time, of these gases was to stream outwards into dwellings.

3. House and street connections should be guarded against the entry of sewer-gases, and means should be taken to dilute such gases freely with air.

4. The downdraught along the sewer in the direction of its fall is very favourable to this dilution with atmospheric-air and to the exclusion of the sewer-gas from the lungs of the population, and every means should be taken to render the draught as powerful and as constant as possible.

G. R. R.

Apparatus for securing the Traps of Siphons and Water-closets against the Penetration of Sewer-Gas into Dwellings.

By Dr. RENK, of Munich.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1882, p. 78.)

The Author refers to the numerous contrivances for the exclusion of sewer-gas from houses, and shows that medical men have with tolerable unanimity proclaimed that certain diseased conditions have been found to prevail in those dwellings where sanitary precautions of this kind were disregarded. The plan usually adopted for the retention of the gas is the introduction of a water-seal of a few centimetres in depth to all the orifices of pipes opening into houses. What the exact depth of such seal should be appears to be by no means clearly understood, for, while 3, 2, and even 1 centimetre (0·39 inch) is considered sufficient in water-closet-traps, a depth of 7 centimetres (2·75 inches) is required for sink-traps, urinal-pans, &c. (by the regulations of Frankfort, Berlin, Munich, and other towns). There are no rules to determine the existing pressures exerted on water-traps under various conditions, and the fact of their inability to withstand exceptional pressures only now and then, becomes apparent when failures occur. The Author states, as the result of his experiments, that, under the most unfavourable circumstances, differences in pressure between the atmosphere in the dwelling and in the soil-pipes may amount to the equivalent of a column of water of 10 centimetres (3·93 inches), 20 centimetres, and even 30 centimetres in height, such pressures as these being clearly fatal to every kind of trap now practicable. These extraordinary pressures arise when large volumes of fluids are thrown into closets, so as to fill the entire cross-section of the soil-pipe, causing it to run full; the water then acts like the plunger of a pump, and produces a vacuum behind it and a pressure in front. By means of a glass model the above action was explained, and the relief afforded by carrying the top of the soil-pipe above the roof was shown. It became evident that where several closets opened

into the same soil-pipe the traps in the upper ones could readily be emptied by suction, while those of the lower closets were forcibly burst up by the compressed air. In either of these cases sewer-gases may escape into dwellings, and it becomes necessary to guard against such accidents by proper appliances. The emptying of a siphon-trap by suction can be prevented by making the inlet-pipe into the trap smaller in diameter than the exit-pipe, so that the latter can never run full. A similar result can be ensured by the adoption of the ventilator designed by Councillor Pettenkofer, and placed above the top of the bend of the siphon. This ventilator consists of a small cylindrical box, from 6 to 7 centimetres (2·3 inches to 2·7 inches) in diameter, and 8 centimetres (3·15 inches) in height. This vessel is hermetically closed, and is penetrated by two pipes of from 1·5 to 2 centimetres (0·59 inch to 0·78 inch) in diameter, one of which passes through the top of the box, and the other through the bottom. These pipes overlap each other in the centre of the vessel by about 1 centimetre (0·39 inch). On pouring water into the vessel it is evident that, on reaching the level of the top of the pipe which passes through the bottom of the box, the water will flow away, and the liquid therefore stands at this level, the other pipe dipping into it to a depth of 1 centimetre. It will be seen also that when any vacuum arises in the soil-pipe tending to wave out the closet-trap, the regulator, which has a seal of only 1 centimetre in depth, yields at once, and provides a ready means for the inlet of air. If, on the other hand, the air in the soil-pipe becomes compressed, the effect on the regulator is to drive the water from the large vessel into the upper pipe, and a seal of considerable depth is provided which increases with the difference in sectional area between the containing vessel and the pipe.

The emptying of one siphon by the action of another can be prevented in several ways, the best of which is to prolong the soil-pipe in its full diameter to the top of the roof with an open end; another plan is to give the soil-pipe a larger diameter than that of the siphon. An objection to the Pettenkofer regulator is that in the summer months the water in it rapidly evaporates, and as this may happen in three or four days, and no warning is given, it is necessary to use some fluid which evaporates very slowly. After various experiments a mixture of 90 volumes of glycerine and 10 volumes of water was found to be the best for this purpose. In order to avoid other difficulties which may occur in the use of the apparatus, such as the spurting out of the liquid or the clogging up of the pipes with fat, when applied to sink-traps, sundry modifications are shown. The Author refers to the danger of breaking the siphon-trap by rarefaction of the gases in the soil-pipe, and states that rain-water pipes opening into the foot of a soil-pipe which has a contracted outlet into the main-sewer, sometimes cause the closet-traps to become emptied. The best plan to obviate this is to provide an independent ventilating-pipe from the foot of the soil-pipe, or at any rate below the lowest closet-trap.

As the result of some experiments with a street urinal-trap, the Author states that it is not necessary that this ventilating-pipe should have the same sectional area as the soil-pipe. Dr. Lissauer of Dantzic, in the discussion on this Paper, described his own experiments bearing upon this question, referred to in his paper¹ on this subject.

G. R. R.

Mouras' Automatic Scavenger. By ABBÉ F. MOIGNO.

(Cosmos, Dec. 1881, p. 622, Jan. 1882, p. 97).

The Author describes the dangers to public health caused by a concentration of large populations in cities, and calls attention to the want of success which had attended all the known systems of sewage purification and utilisation. He quotes the opinion of M. Allain Targé to the effect that all the plans hitherto investigated by the authorities of the City of Paris had utterly failed, and announces the invention of M. Mouras as "a complete solution of the problem which for centuries had been an insolent menace hurled in the face of all humanity." He says that the apparatus, which has been in use by the inventor for twenty years, is "the most simple, the most beautiful, and, perhaps, the grandest of modern inventions," and that, in speaking of it in these terms, he is under- rather than over-stating his case, for each day reveals a new cause of perfection in this mysterious contrivance. The description has been delayed for some months owing to certain technical errors in the applications for patents in France and in other countries, but these difficulties have now been removed, and he is at liberty to publish the nature of the invention. Before doing so he alludes to a fact which, though little known, is extremely instructive. Naturalists have introduced aquariums, containing either fresh or salt-water, filled with animals, for the purpose of study, and the curator of the Zoological Gardens of London, who first employed them, was surprised to see that his cherished fish speedily died, and that his aquarium was in reality only a tomb. It was an aggregation of living animals in which the functions of the scavenger were not provided for, and the fish died, poisoned by their own unhealthy dejections. What was to be done? It was found that by invoking the aid of molluscs, zoophytes, and aquatic plants, which live upon and decompose animal dejections, the necessary scavengers were obtained and the mortality ceased. Here then was a fine example to follow. Eliminate the human dejections by disinfecting them and rendering them fertile. Let everything be transformed on the spot, let everything be emptied away without any loss—the whole made useful, and thus turn death into life. All this the automatic scavenger of M. Louis

¹ *Vide Minutes of Proceedings Inst. C.E., vol. lxvi., p. 447.*

Mouras effects for human populations, however numerous and however dense they may be. The scavenger is in fact—1st. Hermetically sealed and closed by the most inviolable of seals—the hydraulic seal; its contents are therefore shut off from all possible contact with the surrounding atmosphere. 2nd. It is absolutely inodorous, and renders every kind of infection impossible. 3rd. By a mysterious operation, and one which reveals an entirely novel principle, it rapidly transforms all it receives into a homogenous fluid, only slightly turbid, and which holds all the solid matters in suspension in the form of scarcely visible filaments. There is moreover no deposit of any kind, either in the discharge-pipe or the sewer. 4th. It is self-emptying and continuous in its working, that is to say for each new addition from the soil-pipe an equal volume of the contents, duly transformed and prepared, passes away into the sewer. 5th. The liquid which escapes, while it contains all the organic and inorganic elements of the feces, is almost devoid of smell, and can be received into a watering-cart for horticultural purposes, or may pass away into the sewers for use in irrigation. The Author refers to the great advantages resulting from the foregoing facts, and states that they are obtained by means of an inexpensive and very simple addition to the appliances already in use (in France). All that is needed is to render the cesspool watertight, to slightly prolong the soil-pipe so as to dip a few inches into the liquid contents of the cesspool, which are kept at a uniform level, and to add a discharge-pipe, which shall also have its upper extremity beneath the surface of the liquid, but so contrived that it dips slightly downwards, the other end being carried into the sewer, or into a receptacle for liquid manure. Having thus fitted up the apparatus, a constant and automatic scavenging process is the necessary result of the impenetrability and irresistible incompressibility of the liquid contents.

In a subsequent number M. Moigno describes the action of the cesspool by reference to a woodcut. He states that almost any material may be employed in the construction of the tank, the only condition being that the receptacle must be absolutely impervious to water and to air, and he states that arrangements are being made to supply them either in zinc or in galvanized iron of every size and shape. A vessel capable of containing 1 cubic metre (about 220 gallons) is sufficient for a household of from 20 to 25 persons. Passing on to the theory of the action, which is at present obscure, the Author states that it is well known that few things are more insoluble in water than fecal matters, which is due to the fact that they are encased in a species of mucous or fatty envelope, which preserves them from contact with fluids, but he believes that in the air-tight cesspool the solvent action of sulphuretted hydrogen is called into play, and that a species of putrid fermentation is set up which effects the liquefaction of the solid feces. The liquid flowing from the cesspool has a faint odour of this gas, suggestive slightly of the smell of vulcanised india-rubber. But this is but a hasty conclusion, and the whole matter is well worthy of the con-

sideration of chemists. May not the unseen agents be those vibrions or anærobies, which, according to Pasteur, are destroyed by oxygen, and only manifest their activity in vessels from which the air is excluded?

Daily observations conducted with a glass laboratory-scavenger have been made, and from these it results that fœcal matters introduced on the 29th of August were entirely dissolved on the 16th September. Even kitchen refuse, onion peelings, &c., which at first floated on the surface, descended after a time to the bottom of the vessel to await decomposition. Everything capable of being dissolved acted in a similar way, and even paper wholly disappeared. To test the evolution of gas an india-rubber tube was inserted in the lid of the glass model, but was so adjusted as not to dip into the liquid; to the other end was attached an empty bladder. Not only did this bladder continue without signs of inflation, but it became, if anything, more exhausted consequent upon the absorption of oxygen. This experiment is of great importance, and is a complete answer to the fears expressed by Messrs. Alphand and Durand-Claye (engineers to the City of Paris), that gases might be given off which would exert an injurious pressure on the structure. On the free admission of the atmosphere a speedy change was observed; at first small bubbles began to form, and on closing up the apparatus the bladder became about one-third full of noxious gases. The exclusion of the atmosphere is therefore a necessary condition of success. It has been also noticed that the more water is passed into the cesspool the more rapid and complete is the destruction of the suspended matters, and it remains to be seen what quantity of water can most advantageously be used to give the best results on a large scale. The Author concludes with an estimate of the cost of applying the system to the whole of Paris. There are 80,000 cesspools of all sizes in the city, and he suggests that the municipal authorities should acquire the right to use the invention for the whole term of the patent for £2 per cesspool, and charge an annual license fee to each householder of £1. By this means, after the end of the second year, the city would have recouped itself for the first outlay, and would receive for the future an annual payment of £80,000. The work of scavenging would be far better performed than at present, the householders would be saved a vast amount of trouble and expense, and the fœcal matters of the population would become at once available for irrigation.

G. R. R.

Notes on the Cost of Inland Navigation.¹

Collated by GUSTAV MEYER.

(Supplement to the Zeitschrift des Architekten und Ingenieur Vereins zu Hannover, 1881.)

At a meeting of the Society of German Architects and Engineers held at Munich in 1876, it was resolved to invite communications on the above subject; and in 1878, at Dresden, it was decided to collate and publish the information thus obtained.

Fifteen reports were received through various German technical societies, relating to rivers in all parts of the empire.

The information, in each instance, is separated under the following heads; viz., Description of waterway, period of stoppage by ice, direction of the main trade. Original cost and maintenance of navigable channels, description and amount of freight. Description of vessels, their speed, time lost at locks, length and duration of voyages, lading, &c. Cost of building and outfitting vessels, and wages of boatmen. Comparative cost of various modes of progression, viz., by sailing, towing by man or horse, steam tugs, &c.

Report No. 1.—After describing the course of the river Memel through Prussian territory, and its division into two branches at about 9½ miles below Tilsit, gives the tonnage and classes of freight passing up and down stream at that place; the amount in 1876 being 178,864 tons. The Kurische boat and the Boydaoko are the vessels usually engaged in trading; the dimensions of these are given and their burthen, which averages 80 and 75 tons, the largest being 120 and 100 tons respectively.

Report No. 2.—The distance from Königsberg to Memel, via the rivers Pregel and Deime and the Kurische Haff (haven), is 112 miles; and from Königsberg to Tilsit (after leaving the Kurische Haff, passing up the Nemouien, the Seckenburg Canal, and the rivers Gilge and Memel), is 91 miles.

The character of the streams and canals passed through are described, and the average depths and rate of current, also the favourable conditions for navigation.

In 1877 the tonnage entering Memel was 113,800 tons; clearing from Memel was 81,850 tons; raft timber, 193,700 tons.

There are three descriptions of sailing vessels; the first (Reiskahn) of about 100 tons burthen, the second (Wittin) up to 150 tons, and the third (Oderkahn) up to 250 tons; the cost of this latter would be £700 when new. On some part of the waters (Friedrichsgraben) steamers are not permitted. These latter, where used, have engines of about 50 HP. Details are given of the wages of the various crews.

Report No. 3, River Pregel.—The length of waterway between Insterburg and Königsberg is 75 miles, averaging 75 feet 6 inches in breadth above the confluence of the river Alle, and 148 to

¹ Vide ante p. 278, and post p. 369.

184 feet below the latter. Navigation is stopped during from four to five months in the year. The vessels are generally of about 125 tons burthen, worked by from three to six men, according as the journey is with or against stream, and the condition of the river.

Report No. 4.—The Alle is navigable from Friedland to its emptying into the Pregel, near Wehlau, a distance of $33\frac{1}{2}$ miles; timber rafts, however, are brought down from Heilsberg. The breadths and depths of the stream at various points are given. Navigation is open from mid-April to the beginning of November. The trade is principally in bricks.

At Wehlau, in 1877, the tonnage of ships passing down stream was 22,300 tons, carrying a freight of 19,400 tons; passing up stream, 25,100 tons, carrying a freight of 4,400 tons. The average tonnage of ship being 45 tons, and the actual freight 22·5 tons, or 50 per cent. of capability. Vessels up to 110 tons burthen trade in the lower part of the stream. Details of cost of vessel and wages of crew are given.

Report Nos. 5 and 6.—This system of canals forms a connection between the Elbe and the highland districts of Liebemühl, Osterode, Deutsch-Eylau, and Saalfeld. It is altogether $123\frac{1}{2}$ miles long, of which, however, only 28 miles are artificial canal, connecting a chain of lakes. There is a difference of 326 feet 6 inches in the water level of the ends of the northern section of the system, viz., between Drausen and the Pinnau-See. Here there are five locks and four inclined planes, the latter with falls in their length of from 67 feet to 80 feet 4 inches, or a total of 281 feet. There are also three locks on the lower section of the system. The canal is 25 feet broad at the bottom, and 53 feet 6 inches at the top, with a depth of from 4 feet 1 inch to 5 feet 5 inches. The navigation is open from seven and a half to eight months in the year. The total cost of works was £212,326 7s., which, if considered as expended entirely upon the canal portion (28 miles) would amount to £7,596 10s. per mile. Of this an amount of £97,000 is for the four inclined planes (average £24,250 each); therefore the total rise in the canal being 326·5 feet, the cost is £650·3 per foot of rise.

The mean of the maintenance and working expenses is £3,359 2s. per annum. A great portion of this amount (43 per cent.) is absorbed by the maintenance and working of the inclined planes. (It is, however, proposed to replace five of the locks by another inclined plane.) The limit of lading for vessels passing over these inclines is 50 tons.

Report No. 7.—This canal extends from Rothebude on the Vistula to Platenhof on the Tiege (7·4 miles), and from there to Stobbenhof on the Frischen Haff, a further 4·6 miles, or altogether 12 miles. Here are two locks, each 132 feet long and 20 feet 9 inches broad.

The canal is 37 feet broad at bottom and 60 feet at top, and about 6 feet deep. Steam-tugs are permitted, but the speed must not exceed 3 miles per hour, nor the train of barges a length of 410 feet.

Report No. 8.—The navigation of the Vistula extends to above Warsaw, but the portion here considered is that below Thorn (140 miles above Dantzic). The breadth of navigable channel at various points is given, also the depths, fall, and velocity of current. The returns of tonnage of shipping for 1877 are given, with a description of the vessels, which are of four classes, from 50 to 160 tons burthen, &c.

Report No. 9.—This includes the navigation of the Spree, the Landwehr canal, the Berlin, Spandau canal, &c. The Spree is navigable for about 111 miles above its junction with the Havel. The navigation passes to the south of Berlin by a side channel (Kupfergraben). A second channel is formed by the Landwehr canal, which leaves the left bank of the Spree above the city and joins it again below, at Charlottenburg.

The Berlin Spandau canal ($7\frac{1}{2}$ miles long) leaves the right bank of the Spree at Humboldt's Haven, and communicates with the Havel by joining the Tegel Lake above Spandau. Above Berlin the Spree is connected with the Oder by the Frederic William, or Müllroser canal, $14\frac{1}{2}$ miles long, 37 feet broad, and 5 feet 2 inches deep. There are nine locks, of which eight are on the Oder side of the water-shed.

Below Berlin, the Havel, into which the Spree and Spandau canals open, forms the most important water approach to the city. The Plauer and the Ihle canals make a connection between it and the Elbe, and together with the Finow canal communicate with the Oder and Vistula. The lengths and sectional dimensions of these canals are given; also copious information regarding shipping freights, &c.

Report Nos. 10 and 11.—The Elbe, which is a continuation of the Moldau, is navigable throughout its length, and for the largest of its craft from Aussig to Hamburg ($415\frac{1}{2}$ miles). A list of the most important tributary canals and streams is given, also a Table of the number of days in the years 1874–76 in which the river was navigable for vessels of various draughts. The practice of towing vessels by men or horses is almost abandoned. Paddle steam-tugs are used in the Lower Elbe, and a few passenger steamers. Sketches and description of tug-boat and "Zille" are given; also a Table of the number of vessels afloat (of from 30 to 450 tons) for the years 1872–75, and their dimensions.

Other statistical and comparative Tables are given.

Report No. 12.—The navigation of the upper portion of the Weser is only open about two hundred and fifty days in the year, being liable to interruption from drought. The falls, which vary from 1 in 1,800 to 1 in 4,630, are given between Münden and Bremen.

Between Münden and Holzminden the craft are of three kinds, varying from 80 to 200 tons burthen, increasing to 260 tons below this. The proportion of laden vessels proceeding down stream is as 6 to 1 bound up stream. A return of shipping passing Hameln is given for 1877, &c.

Report No. 13.—This canal and the rivers Soeste and Aper-Diep are almost exclusively used for the transport of turf. The rate of water-flow is very slow, and the boats are generally towed by man power. A small tug-boat of 8 HP. is also used.

The boats (*Muttschiffe*) are flat-bottomed, 25 to 26 tons burthen, but seldom carrying more than 15 tons, and when hand-towed have an average speed of from 1 to $1\frac{1}{2}$ mile per hour. Four men load a barge with 15 tons of turf in from seven to eight hours, and are paid at the rate of 1s. 6d. per man per load.

Report No. 14, Alsace-Lorraine.—Five main canals, and as many branch ones, are comprised in this system, which includes the Saarkohl, Rhine and Marne, Rhine and Rhone canals, &c.

Their lengths (total $237\frac{1}{3}$ miles), tonnage of freight conveyed on each, &c., are tabulated comparatively for the years 1872–73. The breadth and depth of canals are given, the boat-draught being limited to 4 feet 6 inches. The cost of maintenance per kilometre for the years 1872–73–74 is given, and a third Table gives the cost of maintenance of each per annum, the average per mile being £67 11s. (839·3 marks per kilometre), exclusive of new works.

Table 5 gives a description of the boats, with their dimensions, burthen, &c.; also the cost of freight between Saarbrück and various towns, the price per ton-mile varying from 0·243d. to 0·37d. (1·29 to 1·95 pfennige per ton-kilometre).¹

Report No. 15, France.—The cost is given of the voyage of a vessel of 260 tons from Mons to Villette (Paris), which averages 0·28d. per ton-mile (including interest on capital, towing, &c.); the time occupied in going and returning being three months. The cost of different classes of freight on the various sections of the canal is given.

A general review of the various reports is made by the compiler, and includes a comparative Table (No. 1) of the character of the vessels, the number of days per annum that the waterways are navigable, the number of voyages made annually, the average proportion of nett to gross load, &c.

A second Table gives the burthen of the vessels, the cost of the hull, rigging, &c., repairs, interest on capital, &c.; and another Table gives a comparative summary of information of the mean duration and lengths of voyages, value of vessel, crews' wages, &c., for the rivers Memel and Elbe, and the waterways between Berlin and Stettin.

D. G.

¹ The value of the mark is assumed as 1s., and of the pfennig as 100th of a mark.

The Tidal Wave and its Effects in the Gulf and Lagoons of Venice. By G. D. Bocci.

(Giornale del Genio civile, 1881, p. 121.)

The Author states that it is of the greatest importance to understand all the phases of the tidal wave in the Venetian gulf, the highest, lowest and mean tide levels, the current along the shore, within the lagoons, at the mouths and along the beds of the rivers, in order to explain one of the causes of erosion or silting up in the lagoons and at the river mouths, and to determine the action of fresh-water flow and the gradients in the tidal portions of the rivers.

In the Venetian lagoon there is only one tide gauge, which is situated $4\frac{1}{2}$ kilometres from the shore. Four observations are taken daily, in addition to the graphic records, two at high and two at low water. Twice in the lunar month, at the moon's quarter, there is no tide.

The Author in comparing and tabulating the records has taken into account the following periods:—

(a) Anterior equinoctial period	. . . . .	} Spring.
(b) Posterior " "	. . . . .
(c) Anterior solstitial " "	. . . . .	} Summer.
(d) Posterior " "	. . . . .
(e), (f), (g), (h), the corresponding periods in Autumn and Winter.		

If the ecliptic be divided in the four points of the equinoxes and solstices, and at points intermediate to the four half-way points between them, there will result eight parts giving the periods indicated above. The ephemeris gives the day and hour of the equinoxes and solstices, and by halving the time between them the time of each period for any year can be obtained.

In the open sea the time of flow or ebb tide is 6·12 hours. In the Adriatic the time is very irregular. The Author gives tables of tidal observations for a period of three years, from which he deduces the following results: That the periods *a* and *d* correspond to the periods *e* and *h*; and *b* and *f* to *c* and *g*. The mean height of high water above a specified datum, is—

For periods <i>a</i> , <i>c</i> and <i>d</i> , <i>h</i>	. . . . .	4·839
" <i>b</i> , <i>f</i> " <i>c</i> , <i>g</i>	. . . . .	5·003
Which gives mean high-water	. . . . .	4·921
The mean height of low water found in a)	} 3·018	
similar manner is		

or 1·903 foot lower than high water. This last figure is, therefore the mean height of the tidal wave. From a Table showing the number of days in the year on which the tide reached certain levels, he shows the tides which have a sensible influence on the rivers vary from 1·64 foot to 5·774 feet, or a range of 4·134 feet,

from 3·281 feet below mid-sea level to 0·853 foot above it, while the maximum range was from 4·593 feet below to 4·331 above mid-level. The mean of the oscillation affecting the rivers is 3·7074, which differs from mean sea-level (3·97 feet) by 0·26 foot.

The Author then shows that at the autumnal equinox the high water (5·043 feet), is lower than at the winter solstice (5·315); and at the spring equinox (4·869) less than at the summer solstice (4·905); at the two equinoxes (4·954), less than at the two solstices (5·108); and at new and full moon (5·387), the high water is sensibly higher than at the quarters (4·679). The ebb tide is lower (2·89), at the spring equinox than at the other seasons; at new and full moon low tide (2·812), is lower than at the quarters (3·412); whence these corollaries—

1st. For mean low and mean high water, spring and autumn are favourable to the rivers though by only 0·13 to 0·16 foot.

2nd. From the same point of view, the high tides at the moon's quarters and the low tides at new and full are more favourable by about 0·66 foot.

3rd. The mean range of the tidal wave in the above-named four seasons of the year is nearly equal, being respectively 1·89; 1·982; 1·778; 2·041 feet; while at new and full moon it is 2·575, and at the quarters 1·266, of which the mean is 1·920. The mean sea-level from these figures is 4·072, which differs little from that previously found. The tide takes longer to flow than to ebb, and the sea-level is above the mean for a longer period than below it, the difference during the month of June, 1876, amounting to sixteen hours.

The Author then deals with the lagoon of Chioggia.¹ The tidal wave passes up the Adriatic with a velocity of $26\frac{1}{4}$ feet per second. At the equator, in open sea of indefinite depth, the velocity is 1,446 feet per second. According to Maury, at depths of 24,000, 3,300, 1,300, 330, 164, 33 and 3·28 feet, the velocities per hour are respectively 500, 250, 160, 80, 57, 25 and 8 geographical miles. The mean height of the tidal wave during the month of June, 1876, was 1·45 foot at Chioggia, and 1·67 foot at Brondolo. The principal sea-levels at Brondolo with respect to the mean sea-level are; mean high water, 0·951 foot above it, mean low water, 0·951 foot below; maximum high tide 4·954 feet above, minimum low tide 3·642 feet below.

After discussing the action of the tidal wave in passing up a river, the Author points out the difference between this and its action in a lagoon, in which, instead of encountering a descending body of water, it is opposed by the water held back in the lagoon, and finally expends its *vis viva* against the shore. This extinction of *vis viva* explains many of the phenomena of water in motion. To it are due, for instance, whirlpools, secondary and opposite currents formed by water in motion encountering obstacles, the transformation of waves of oscillation into waves of translation, the formation

¹ Vide Minutes of Proceedings Inst. C.E., vol. l., p. 219; vol. lvii., p. 361.

of basins and lagoonal craters, which are exceptionally deep near the shore, and a phenomenon not previously observed, that the extent of rise and fall is greater near the perimeter than at the entrance of lagoons of limited extent. It would seem that the height of the tidal wave ought to gradually diminish as it spreads over a lagoon, but to what extent would depend upon a variety of causes, the number and depth of the channels and so on, and that in lagoons of great extent, or great in proportion to the size of the entrance, at the extremity the tidal action would cease altogether.

The Author then discusses the relation between the rise and fall of the tide outside and inside the lagoon. He considers that the entrance is partly free and partly drowned. Let $o Y$ be the section of the entrance of a lagoon, $m m$ mean high, $n n$ mean low water; a their distance apart, b the height from the bottom of the entrance to low water, h the difference between this low water and that $p p$ of the water at a great distance in the lagoon (of indefinite extent) being the unknown quantity, and let x be the variable height of the surface PP of the sea-level above $n n$. Flood tide begins when the sea-level PP rises above, and ends when it falls below the level in the lagoon $p p$. It is clear that the flow from $p p$ to $m m$ is equal to that which takes place during the return movement of PP from $m m$ to $p p$. The velocity of efflux in the free opening $(x-h)$ is $v = \frac{2}{3} \sqrt{2g(x-h)}$, the discharge in a unit of time is $p = \frac{2}{3} l (x-h) \sqrt{2g(x-h)}$, l being the width of the entrance. The discharge of the drowned entrance

$$p_1 = l (h+b) \sqrt{2g(x-h)},$$

whence the total discharge of the semi-flood in a unit of time is $p + p_1 = p = \frac{1}{3} l (2x+h+3b) \sqrt{2g(x-h)}$, and during an infinitesimal time dt , $dp = \frac{1}{3} l (2x+3b+h) \sqrt{2g(x-h)} \times dt$, but the heights of water x being proportional to the time (or supposed to be so) $dt = \mu dx$, μ being any constant. Hence the Author obtains the following results:—

$$p = \frac{2}{3} \mu l \sqrt{2g} (a-h) \sqrt{a-h} \left(\frac{2}{5} a + \frac{3}{5} h + b \right) \quad (1)$$

Proceeding in a similar way for the ebb tide, he obtains

$$p = \frac{2}{45} l \mu \sqrt{2g} \left(21 h^{\frac{5}{2}} + 15 . b . h^{\frac{3}{2}} \right) \quad (2)$$

Equating (1) and (2), and reducing

$$\frac{21 h^2 + 15 b}{b a + 10 h + 15 b} \sqrt{\left(\frac{h}{a-h} \right)^3} = 1 \quad (3)$$

and making $h = n a$ (4)

$$\left(\frac{21 n^2 a^2 + 15 b}{b a + 10 n a + 15 b} \right)^2 \left(\frac{n}{1-n} \right)^3 = 1 \quad . \quad . \quad . \quad (5)$$

Hence, for $h=0$; (i.e. when, at low water, the water in the lagoon ceases to be in communication with the sea) the height of the tidal wave and the proportional superelevations will be—

$$\begin{array}{llll} a = 1.241; & 0.865; & 0.555; & 0.354 \\ n = 0.55; & 0.60; & 0.65; & 0.70 \end{array}$$

These results are of the greatest importance in questions relating to rivers. The elevation of the lagoon above the sea is given by $h - \frac{1}{2} a = a (n - 0.50)$. As the depth (b) increases, (n) diminishes. Thus for $b = 5$ metres, $n = 0.52$, whence the superelevation = 0.02, and the tidal oscillation must reach $a = 2.545$ metres, in order that n may = 0.55. For $b = 10$ metres, $a = 0.50$ m, n would be 0.505, hence the advantage of deep entrances.

If the lagoon is of limited extent (and those treated of are very limited in comparison with the entrances), the lagoonal surface has a moderate oscillation with respect to pp , and the properties deduced (true at the limits) are true also in the case of smaller lagoons; that is to say, the mean lagoonal oscillation ought, theoretically, to be higher than the mean sea-level, and this superelevation will be less, as the entrance is deeper. But as the discharges, as above determined algebraically, are greatest for the largest lagoons and diminish with their size, it is clear that the velocity of the water through the entrance follows the same law, and as the removal of the sand is owing to this, the hydraulic aphorism is proved, “a large lagoon makes a good harbour,” and renders more effective the action of the rivers discharging into it.

The Author proceeds to show that for every lagoon there exists a certain size of entrance which is most suitable to it, and that any alteration of this section either in width or depth is detrimental to the lagoon. He then gives particulars of the lagoon of Chioggia. Its area is semicircular of $3\frac{3}{4}$ miles radius, with centre at the entrance. The water-surface at mean sea-level is 14,130 acres. The width of the entrance is 1,666 feet; its area in the year 1811 was 48,500 square feet, and is now 91,500 square feet. The mean discharge is 51,100 cubic feet per second, which at spring tides is increased to 106,000 cubic feet, and at neaps is reduced to less than half.

The waters of the Brenta have discharged into the lagoon since the year 1839, and since then the depth, both in the canals and over the whole area, particularly at the parts furthest from the entrance, has diminished, but the entrance itself has increased in width though not in depth. The difference in velocity between the ebb and flood tide has increased, though both velocities are less than before, owing to the increased area of the entrance, and the

somewhat greater turbidity of the ebb tide. At the present time the velocity of the ebb when the Brenta is not in flood is 0·56 foot per second, and when in flood 1·115, while the velocity of the flood tide is 0·492, giving a mean difference 0·347. Previous to 1839, the velocity of ebb tide was 1·05, and of the flood tide 0·984, a difference of 0·066 foot.

When the tidal ebb and flow are in full action the whole of the water in the lagoon is in motion. In the canals the velocity varies from 3·3 feet to zero. The currents in the shallow water vary much in direction and speed and are greatly influenced by the canals. The velocity is greatest near the entrance, whilst at the most distant parts the motion is hardly perceptible; so much is this the case that some theorists consider that a lagoon consists of two parts, one active, the other stagnant, but the Author considers this opinion to be erroneous, and that even the remotest parts are influenced by the tidal action. The velocity through the entrance should be sufficient to remove or prevent the formation of sand banks in its neighbourhood, while at the same time the section should be large enough to admit tidal water in sufficient quantity to bring the water surface all over the lagoon to the same height, or nearly so, as that of the external sea at the turn of the tide.

W. H. T.

On the Discontinuous Defensive Works on the Middle Lengths of the Po. By A. ZOTTI.

(Giornale del Genio civile, 1882, p. 3.)

The river Po, in the first lengths in which it has been embanked, passes through a valley from 3,000 to 8,000 feet wide, which, during high floods, is submerged to an average depth of 11½ feet. Owing to the soft nature of its bed, the river pursues a winding course, and it frequently happens that, after traversing a considerable distance in a circuitous channel, the stream comes round to a point separated by only a few hundred yards from that at which it diverged from a straight line. In times of flood the river occasionally breaks through this narrow neck of land, thus exchanging a long winding course, with an easy gradient, for a short, straight, and rapid descent.

In the province of Pavia, up to the last few years, private persons were allowed to make artificial channels to lead the river into such courses as they wished, and it is only quite recently that the injury done by such diversions has been recognised and forbidden. The river is now allowed to form its natural channel, and when it persistently encroaches in any direction the retaining embankment is moved farther back; fertile lands are thus abandoned to the river, which takes possession of them for a time, and afterwards by degrees restores them; and it is only when lands

of exceptional value, such as towns and villages, are endangered, that means are adopted to resist the approach of the river. This method has been followed in the district of Rottino, in the commune of Monticelli d'Ongina, in the province of Piacenza, where, within the last thirty years, the embankments have been moved farther back three different times, thereby abandoning to the Po a very fertile zone of land $1\frac{1}{2}$ mile in width; and now, in order to save the fourth embankment and to protect the principal town of the commune, and the towns of Olza and Fogarole, means of defence have been adopted which are described in the present Paper.

The immense cost of constructing and maintaining protective works along the banks of the Po justifies the reluctance which has been felt to incur it hitherto in this district. By examining the processes of nature in the formation of the channel of a large river, it appears that wherever, owing to the superior tenacity of the soil, an obstacle is presented to the water, the erosion of the bank makes no material progress, either above or below, till the obstacle itself has been removed. If, now, such obstacles can be formed artificially and of sufficient strength, at intervals along the bank, they will curb the river without the necessity of forming longitudinal banks from point to point. The difficulty in establishing these isolated points of defence has hitherto been to fix them firmly in the bank, and the danger lest the water should find its way to the back of them, in which case they would become a source of peril instead of protection, by directing the force of the current against the bank. The new system, introduced by the Author some years since in the province of Piacenza, has allowed the construction of a species of defence which solves the problem of arresting extensive erosion, at an expense which, compared to the old system, is very slight.

The distinguishing feature of this form of defence is a monolith of concrete, formed in a kind of strong wickerwork, stiffened by rods and bound together with iron bands. These monoliths are from 16 to 26 feet long, of oval section, with axes of 6 feet 6 inches and 2 feet 6 inches; one end is cut off square, the other is formed into an obtuse conical shape. Moles are formed of these monoliths at intervals along the banks, and if their distances apart are rightly laid out, they form efficient protections to the embankments without the necessity of protecting their whole length.

The method of forming these moles is this. A ditch is dug just inside the natural bank of the river to the depth of ordinary water-level. In this ditch are placed three rows of monoliths at different slopes; the inner $1\frac{1}{4}$ to 1, the middle 1 to 1, the outer $\frac{1}{2}$ to 1; the lengths of the blocks in each row being 16 feet, 23 feet, and 26 feet respectively. As the current attacks and washes away the river-bank, the first row of monoliths gradually sinks into the bed of the river; the second row also sinks, but to a less extent, the third row retaining its original position. This action takes place all along the mole, and a protected slope is thus left to resist the

action of the river. In plan the mole is parallel to the river, with the exception of the up-stream end, which is laid out so as to present a convex surface to the current. The distances apart at which the moles are placed depend upon local circumstances, and vary from 650 yards along straight lengths, to 200 yards where sharp bends occur. The moles are formed, not upon the retaining embankments, but upon the natural bank of the river, at ordinary water-level, leaving some 60 yards or more of cress between the mole and the embankment.

A great advantage in this system of defence is that it can be carried out by degrees. The up-stream, convex portion of the mole, being first constructed, its continuation down stream can be carried just so far as may be required at the time, and prolonged when necessary. The moles, however, should always be built in pairs, leaving such a distance between the two as circumstances may show to be best.

The cost of the two moles specially referred to in this Paper was at the rate of £8 18s. per lineal yard; but these moles, 503 yards long, protect a length of 2,405 yards of river bank; and the cost per yard of bank so protected amounts to £3 4s. The cost in this case was greatly increased owing to the delay which occurred in sanctioning the work.

The Author then gives a list of the various defensive works, upon his own and other systems, which have been executed upon the banks of the Po, from the mouth of the Lambro to $4\frac{1}{2}$ miles below that of the Adda, a length of $42\frac{1}{2}$ miles.

W. H. T.

The Dikes of the Isle of Ré. By MARTIN DE BEAUCÉ.

(Annales des Ponts et Chaussées, 6th series, vol. iii., 1882, p. 136, 2 woodcuts.)

The greater portion of the Isle of Ré is below high-water mark, and is consequently protected from the sea by low dunes, and by dikes having a total length of about 6 miles. These dikes were originally covered, on their sea face, with small stones resting on a layer of clay, which offered little resistance to the waves, and were therefore frequently damaged. A protection of fascines and stakes, which was next tried, had to be abandoned, owing to the rapid decay of these materials. It was then attempted to secure the sea slope with dry masonry pitching laid upon a layer of small stones, from 16 to 20 inches thick, after the method usually adopted in Flanders. Though this kind of protection lasted for some time, breaches were liable to be formed in stormy weather, and, when once begun, they enlarged with marvellous rapidity. It was finally decided, in 1846, to pitch the sea slopes with masonry set in hydraulic mortar, the pitching being made in two courses, each 1 foot thick, the under course being formed with rubble masonry

and the upper with scappled stones. The outer slope of the dikes has an inclination of 2 to 1, and the inner slope $1\frac{1}{2}$ to 1, coated with clay and planted with tamarisks. The dikes are generally $6\frac{1}{2}$ feet wide at the top, and raised 10 feet above the highest tides. A parapet, 2 feet thick, is built on the top of the outer slope, with a parabolic face, so as to throw back the waves, which would otherwise overtop the embankment. The pitching is generally founded on the limestone rock, which forms the subsoil of the island; but where the rock dips too low, the foundations are carried from 10 to 13 feet below the surface to a fairly firm substratum underlying the surface layer of sand. It was found unnecessary to protect the toe of the slope, as at first proposed, in this latter case, as the retreating wave is met by the sea, or by the next wave, before it reaches the bottom. The cost of this last type of dike averages about £3 per lineal yard when the pitching rests on rock, and £4 10s. in other places.

An attempt was made, by means of groynes, to cause a deposit of the sand drifted along by the littoral currents; but though the sand accumulated on the side of the groyne opposed to the current, an erosion of the beach was produced on the other side, so this plan had to be abandoned.

The portions of the old dikes still in existence are reconstructed on the new system when damaged by the sea, and, excepting the cost of these renewals, the yearly cost of maintenance would not exceed about £1,000, as the new type of dike has never been seriously damaged during the period of over twenty years that it has been in existence.

L. V. H.

Dikes on the Lower Rhine. By J. SCHLICHTING.

(Zeitschrift für Bauwesen, 1881, pp. 283 and 391.)

The introductory portion of this Paper is occupied principally with the history of the gradual growth of the extensive system of dikes at present existing on the lower Rhine.

The banks are of two descriptions: *i.e.* "Bann-deiche," dikes to resist the destructive effects of the winter floods and ice floes, which were first constructed, and Sommer-deiche, or Summer-dikes, added for the purpose of reclaiming the wide and fertile tracts of country in the immediate neighbourhood of the river, which was unprotected by the Bann-deiche; the latter owing to the numerous wide-spread branches of the Rhine being in many cases situated at a considerable distance from the existing river-bed. They are lower than the Bann-deiche, but of a height sufficient to afford protection against the ordinary summer floods, while permitting the high floods during the winter months to overflow them and enrich the meadows they enclose with the fertilising

deposit. Their effect has been so beneficial that whereas the construction of new Bann-deiche is on the decline that of the Sommer-deiche is being everywhere prosecuted.

A map accompanying this Paper shows the position of the various Bann- and Sommer-deiche.

The Bann- and Sommer-deiche on the Lower Rhine are constructed principally of the fat clay and loam deposits formed by the river in the course of many centuries, and which are met with in strata of various thicknesses. The cross section of the dikes varies considerably, which fact is attributable to the unsystematic manner in which they were originally made, but in a general way the principles laid down in the Regulations of the 24th February, 1767, have been adhered to, viz., banks to be made of good fat clay, to be taken from the outside, from the inside only when good material is unprocurable within a radius of 188·31 metres (608 feet), in which case no excavation is to be made within 11·30 metres (36 feet) of the toe of the bank, nor to a depth likely to give rise to the formation of springs. The bank is to be made up in layers of from 0·24 to 0·31 metre (9 to 12 inches) in depth sloping up from the river, each layer to be well punned and rolled. If the bank be situated on sandy soil, a trench 2·51 metres (8 feet 2 inches) in width is to be taken out down to the clay and refilled with well-rammed clay. Where existing banks require strengthening, or the slopes flattening, the new material is not to be tipped from the top but spread in layers, each layer being well punned before another is deposited on it. For the purpose of consolidation plank roads, hand rammers, but chiefly horses are employed, the latter being driven backwards and forwards over the ground, which effectually binds each course. All hedges, shrubs, and trees, are to be carefully removed from the body and slopes of the bank. The slopes to be turfed or sown with grass seed. Outside slopes to be 4 to 1, inside 3 to 1, and in sandy soil 6 to 1 is prescribed for the outer slope. Formation width in good soil 3·77 metres (12 feet), the inner edge being 0·31 metre (12 inches) higher than the outer.

Some of the banks are used as roads, but more generally as pasture land, being well covered with grass, which is the best protection against damage in case of an overflow.

The height of the Bann-deiche varies. The rule is 0·31 metre (12 inches) above the highest known flood free of ice, which occurred on the 15th of March, 1876, and rose to 7·50 metres (24 feet 7 inches) above the datum at Rees (R.D.). But, in fact, the banks are much higher than this. It is only within the last few years that they have been levelled over, the information thus gained shows that the repeated additions to them has been productive of considerable variation in the height of the respective banks. Different communities, anxious for their own safety, raised their banks above their neighbours; the latter, not to be outdone, did the same in turn, the consequence is that the majority range from 8·80 to 9·10 metres (28 feet 10 inches to 29 feet 10 inches)

above the R.D., or from 1·30 to 1·60 metre (51 to 63 inches) instead of 12 inches above the flood of 1876.

In course of time the gradual elevation of the river-bed will no doubt necessitate a further increase to the height of the dikes; this will affect the drainage, and steam power may be required for the purpose, or the Bann-deiche will have to be converted into Sommer-deiche, an alternative for which there is much to be said. The road-crossings are innumerable, some are carried over and some, where the bank is high, are carried through, somewhat below the crest, the bank being retained by breast-walls, provided with grooves to receive the timber used in flood time to dam the breach.

The Sommer-deiche are constructed on the same principles, the outer slopes being 4 to 1, the inner 6 to 1, to prevent scour in case of an overflow. The formation width 1·25 to 2·51 metres (4 feet to 8 feet), according to the height, the minimum being 5·34 metres (17½ feet) above R.D., or 5·65 metres (18½ feet), and in some cases where buildings are protected, even as high as the Bann-deiche, provided the width of the river at high flood level be not less than 1,054·5 metres (1,152 yards).

From a Table of the average daily height of the river for the forty-nine years from 1823 to 1871, it appears that the total average was 8 feet 11·85 inches (Prussian feet) above R.D., the highest being 10 feet 4·88 inches, the lowest 6 feet 0·51 inch.

The nature of the channel, with its alternate deep and shoal water, renders the Lower Rhine particularly liable to be dammed up by the floating ice grounding in shallow water and causing a block which soon raises the river to an abnormal height. In this manner several very considerable breaches in the dikes have been caused, notably between Xanten and Wardt, where on the 2nd and 3rd of March, 1855, the bank burst in four places. The water over-topping the crest 0·60 metre (2 feet), and continuing at this height for several hours. The turfed banks, with 3 and 4 to 1 slopes, successfully withstood this flood, those with steeper slopes suffered considerably. At Beck, near Xanten, a chasm to the depth of 18·8 metres (62 feet) was excavated, evidence of which is still visible.

The sluices in the Bann-deiche are exclusively used for draining the upland meadows; the navigable Spoy Canal at Brienon also serves the same purpose. Those in the Sommer-deiche, on the other hand, are principally irrigating sluices, though they are also useful for letting off the floods. The waterway provided is quite arbitrary, being dependent on so many contingencies; where, however, repairs or new work has to be done, the sill is laid according to the Cleves Dike Regulations, 0·31 metre (12 inches) below the bed of the nearest main-drainage canal. These latter are laid out and maintained at the general expense, while the side drains are left to the discretion and care of each proprietor.

Detailed drawings of various types of sluices are given and described. The most important are those on the Spoy Canal,

where the locks are provided with four gates, the two outer regulating, in case of need, the flood water, the two inner the water of the canal. The length of these locks is 43 metres (141 feet), breadth 7 metres (23 feet). The gates are of wood, the inner set being 5 metres (16½ feet), the outer 9 metres (29½ feet) in height, and are worked by a simple rack and pinion arrangement.

The various smaller culverts and sluices are executed in a substantial manner; inverts are the exception, they are closed in various manners, some by movable shutters, others by check gates, and some by planks dropped into a groove in the wing walls.

In the Sommer-deiche irrigation, sluices, to admit the fertilising flood-water from the Rhine, are almost universal, but where they do not exist certain portions of the bank are left lower than the rest and the slopes made flatter, so that the floods can flow over them. These are termed "Ueberläufe," and are generally situated on somewhat higher ground, so that the banks are as low as possible, though sufficiently high to keep out the summer floods. The disadvantage of this mode of irrigation is that should there be no floods in winter, the land does not get watered at all.

The due maintenance of the dikes is the special function of the department in charge of these works, as thereon depends their very existence, any neglect being attended with the most serious consequences, a single weak point often endangering the whole. The Cleve Regulations on this point are most stringent. Twice a year, in spring and autumn, every portion of the protective works has to be visited and inspected in detail by the Deiche-stuhl or Board, in company with the Chief Inspector of Dikes, and a report submitted; accordingly at the spring inspection, in April or May, the repairs necessary to dikes, culverts, sluices, &c., are determined on, estimated for, and given out on contract or day-work, and in October the work done is inspected and passed. All disputes, breaches of the dike regulations, and other matters, are also gone into and settled.

At the breaking up of the ice and during high floods the constant attendance both day and night of the Deiche-gräf and his assistants is prescribed, in cases of extreme danger they are empowered to employ whatever labour or material they may deem necessary, even to stripping the rafters off the houses. They are kept informed daily of the state of the river by telegraph from Düsseldorf through the local authorities. The effect of the waves on the bank is the danger chiefly to be guarded against; besides stopping springs and deterring and making up settlements, they have generally to provide against every preventible accident.

W. A. B.

The Regulation of the Weser and Canalisation of the Fulda.

(Deutsche Bauzeitung, 1881, pp 198, 477.)

The portion of the Weser referred to extends from Münden to Bremen, a distance of about 230 miles, with an average fall at mean water-level of 1 in 3,000.

The systematic improvement of this river commenced in 1823, with the object of securing throughout a depth of $1\frac{1}{2}$ foot only at low-water; but from Münden to Hameln, from Hameln to Minden, and from Minden to Bremen, the depths are 1·64, 2·3 and 2·5 feet respectively at lowest water-levels, and such rarely occur.

From data furnished by the Prussian Government in 1879, it appears that nothing less than a depth of $3\frac{1}{4}$ feet down to Minden, and 4 feet thence to Bremen, would satisfy the then conditions of traffic; but as the Weser is navigated as far up as Minden by vessels drawing $4\frac{1}{2}$ feet of water when fully laden, and above it by vessels drawing 4 feet under similar conditions, it is clear they could not carry full loads at low water. Consequently, rather than reduce the size of the vessels, or work them with half loads, an improvement of the river itself by regulation was proposed, and up to mean water-level the work is nearly completed. The usual methods have been followed, viz., the construction of groynes and parallel training-walls. In the upper reach of the river the bed is very rocky and irregular, having in some places high projections or mounds, in others deep hollows or pools; the result is a heading up and a fall, which constitute a hindrance, and sometimes a danger to navigation.

To remove these ledges or projections by blasting would have been too costly, for some of them are over a mile in length; but by constructing dams of stone ballast and fascines at the necessary points, the water-level at the pools was raised, and an equalisation or uniformity of fall brought about.

Above Hameln a difficult and dangerous obstruction is avoided by the cutting of a canal; and in place of the old lock, which was far too small for existing traffic, a new lock of double its width will be built. Since 1873 nearly £150,000 have been spent on the work, and it is thought that £100,000 more will be required; and even then it seems doubtful, if the river trade increases, whether the objects aimed at can be effected by regulation only, but that canalisation also may be eventually necessary.

The improvement of the Weser rendered that of its tributary, the Fulda, imperative from Cassel (the capital of Hesse) to Münden, a distance of nearly 20 miles. The discharge of the Fulda is only 280 cubic feet, consequently, assuming that an uniform fall of 1 in 800 could be secured by regulation (the average fall is 1 in 1,500), this would give a depth of $1\frac{1}{2}$ foot only, which is manifestly insufficient. Accordingly, canalisation is the method of improvement proposed to be adopted, and seven movable weirs are suggested with locks 180 feet long and 25 feet wide, and thus

capable of admitting the largest vessels that navigate the Weser. Each lock and weir will together cost £10,000, and the estimate for the whole work, including £20,000 for a harbour at Cassel, is £125,000, and the time of completion is put down as from three to four years.

W. H. E.

The Ghent-Terneuzen Canal, and Port of Ghent.¹

By OCT. BRUNEEL and E. BRAUN.

(Le Canal de Terneuzen-Gand et ses Installations Maritimes, 10 pl., 4 woodcuts.)

A short historical account is given of the various endeavours to improve the water communication between Ghent and the sea, dating from 1251, when the town was connected with the Zwyn, and a canal was formed in the bed of the Liève up to Danme, at that time the port of Bruges. The latest route adopted was the Ghent-Terneuzen canal, completed from Sas-de-Gand to Terneuzen in 1827. This canal having become inadequate for the increased draught of vessels, it was decided to enlarge it, in the year 1870, after many delays and discussions.

The first works undertaken consisted in straightening, widening, and deepening the portion of the canal between Ghent and Langerbrugge, and in the Rieme reach. The new section adopted for this portion of the canal was a bottom width of 55 feet 9 inches, a depth of water of 21 feet 4 inches, and slopes of 3 to 1, giving a width of 183 feet 9 inches at the water-level, and 223 feet at the top of the banks, 6½ feet above the water. These works, commenced in 1870, were completed in 1875 for a sum of £49,940. The excavations amounted to 1,449,400 cubic yards. Another section of the enterprise was commenced in 1873, consisting in the straightening and enlarging another portion of the canal similarly to the first. The works were contracted for by MM. Couvreux and Hersent for £117,330. The total amount of earthwork was about 2,880,000 cubic yards. The works also comprised a swing-bridge having a clear span of 26½ feet, and other minor works. The enlargement of another portion of the canal, 480 feet in length, was commenced in 1875 for a sum of £9,032; it included the rebuilding of Langerbrugge swing-bridge, and other works which were completed in 1876. In this latter year the enlargement of another portion of the canal, 4,421 yards in length, was commenced, together with some bridges and other works. The contract was taken by Messrs. Couvreux and Hersent for £91,640. The total quantity of earthwork and dredging in this portion was about 1,465,000 cubic yards, which, with the excavations in the other portion undertaken by the same contractors, amounted to about 4,345,000 cubic yards, of which about 1,560,000 cubic yards were removed by wheelbarrows, 285,000 cubic yards by excavators, and 2,500,000 cubic yards were dredged. The Authors describe

¹ Vide ante p. 278 and p. 353.

and give illustrations of the excavator and dredger with long discharging shoot used on the works by Messrs. Couvreux and Hersent, of which descriptions have been previously given in the Minutes of Proceedings.¹ The excavator, with its chain of buckets and steam-engine, had been previously employed by M. Couvreux on the Suez Canal, and on the Danube regulation works. The rails were laid for it on the ground, previously excavated to the water-level, for a distance of nearly 3 miles along the line of the canal. The long shoot was a simplification of the method employed for discharging the dredged material at the Suez Canal works, by using a pump for raising and driving the material mixed with water down the shoot. When the bank was too far off to be reached by the long shoot, the material was discharged into barges, from which it was again lifted by a chain of buckets working on either a fixed or floating stage, to which the long shoot could be attached if desired. The diameter of the shoot was $1\frac{1}{2}$ foot. When the place of deposit was about 1,000 to 1,300 feet distant, the shoot was made to discharge into an open shoot, placed on the ground, with a fall of only 1 in 100, which sufficed for discharging the material except when large stones from old banks happened to be drawn through the first shoot. Some of the dredged material was deposited in iron hopper barges 82 feet long, $14\frac{3}{4}$ feet broad, and 1 foot 8 inches deep. The inner part, which contained the material, was so shaped that the discharging buckets could remove the whole contents without injuring the plate-iron sides. These barges were also used for filling up, under water, the abandoned portions of the canal; their double bottom had been pierced by pipes 1 foot in diameter, and placed 13 feet apart, and when the material was to be discharged, the plugs closing the pipes were raised and water pumped into the barge, which forced the material out of the holes. The barge rose in the water as the material was discharged, till at last the hopper was left empty and clean, with its bottom above the water-level. These barges held about 65 cubic yards; they were emptied in ten to fifteen minutes, and they could raise the bank to within 5 feet of the surface.

Another ingenious method was employed for discharging the dredged material. A well was placed under the buckets for receiving the material, into which a stream of water was forced by a powerful rotatory pump. The mixture of silt and water thus formed flowed from the bottom of the well into a jointed pipe, 1 foot in diameter, which floated for a certain distance on the top of the water. A centrifugal pump placed at the middle of this pipe increased by suction the discharge from the well, and raised it to a height of 28 feet, from whence it was poured into an open shoot which conveyed it several hundred yards farther. The centrifugal pump, driven by a 20-HP. engine, was 430 feet from the dredger, and the end of the pipe 230 feet farther off. A second pump was subsequently introduced into the pipe, which enabled the material to be discharged at a distance of about 1,100 yards

¹ *Vide Minutes of Proceedings Inst. C.E.*, vol. lv., p. 378.

from the dredger. Messrs. Couvreux and Hersent completed their contract at the close of 1878. The final works for completing the enlargement of the canal to the Belgian frontier were commenced in 1878. They included the diversion of the Ghent and Eecloo Railway, and the construction of two bridges, besides other works. The excavations amounted to about 260,000 cubic yards. The foundations of the piers of the swing portions of the new bridges were laid by means of bottomless caissons sunk by compressed air. The works cost £41,280, and were completed in April 1881.

The enlargement of the portion of the canal within Dutch territory, from Sas-de-Gand to the Scheldt, has been the subject of prolonged negotiations and discussions; but a convention was at last agreed to in 1880, the land is being acquired, and it is expected that the works will be completed by the end of 1883.

The Authors give a detailed account of the rise and progress of the port of Ghent. The first dock was commenced shortly after the completion of the Ghent-Terneuzen Canal, and was completed in 1828. This dock, 5,580 feet long and 197 feet wide at the water line, and 131 feet at the bottom, with an average depth of $14\frac{1}{2}$ feet, joined the Ghent-Terneuzen and the Ghent-Bruges canals at one end, and the Scheldt and the Lys at the other end. Quays, sidings, warehouses, and sheds were provided by degrees, and hydraulic machinery was introduced in 1870. A timber pond was constructed in 1880 opening out of the dock; the excavation was effected by a bucket-dredger, and the material was discharged by mixing it with water and pumping it, by means of a centrifugal pump, through a line of flexible floating tubes, after the method adopted on the Amsterdam canal works.¹ The material was discharged in this manner to a distance of about 650 feet on to banks $6\frac{1}{2}$ feet high. When the height of discharge exceeded $8\frac{1}{2}$ feet, the system had to be modified. The material flowing through the tubes was led into a reservoir near the bank, from which it was pumped and discharged by a powerful centrifugal pump. By this method 100 cubic yards of excavation were discharged on the average per hour.

The following works are being carried out, namely, the deepening of the dock, its enlargement to a width of 295 feet, and an extension of its quays; the enlargement of the outer harbour between the dock and the Ghent-Terneuzen canal, and the formation of quays round it; the construction of warehouses, sheds, &c., and the rebuilding of Muide bridge. The depth of water along the quay walls will be 24 feet 7 inches.

The increase in the trade of the port of Ghent is illustrated by several tables and two diagrams. The average annual tonnage of the vessels trading with the port, which between 1841 and 1850 was 28,021 tons, increased to 155,686 tons for the ten years from 1871 to 1880, both the number of vessels and their average tonnage having considerably more than doubled.

L. V. H.

¹ *Vide Minutes of Proceedings Inst. C.E.*, vol. lxi., p. 6.

The Dry-Docks in the Naval Arsenal at Spezzia.

(Giornale del Genio civile, June 1881, p. 225.)

In selecting a site for this work, two conditions were considered essential; first, that the foundations should be good; second, that the works should be executed in dry ground. After careful examination, such a site was found. Its surface was 5 feet above mean sea-level; the geological strata were—vegetable soil 5 feet, sand and gravel 6 feet 6 inches, stiff clay 6 feet 8 inches; below this a thin layer of gravel and sand, then fine sand with grains of quartz down to 50 feet below mean sea-level, resting upon a compact mass of clay of unknown thickness.

Four parallel docks were constructed, 164 feet apart from centre to centre, each of the two outer docks being 361 feet long at the coping, and 298 feet at the floor-level; the two inner were 433 feet and 359 feet at these levels. They are all 41 feet wide at the floor-level; the outer pair 93 feet, and the inner 100 feet at the coping. The floor has a fall of 1 in 100 towards the entrance. The sides are formed in steps 2 feet 7½ inches wide, and 5 feet 3 inches high, with a batter of 8 inches; there are eight stairways, two at each side and two at each end. The entrances to the smaller docks are 52½ feet wide at the bottom, 75 feet at the coping; to the larger, 58 feet and 80 feet at the same levels. The length of the entrance-chamber is 46 feet in the smaller, and 50 feet in the larger pair. Sill-level is 30 feet below mean sea-level. Two tunnels, 3½ feet wide and 6½ feet high, are carried under the side-walls of each dock for the purpose of emptying it, and to drain any water that may leak through the masonry. Water is admitted from the wet dock by means of valves in circular horizontal tunnels 2 feet 8 inches in diameter leading into vertical shafts. The valves are wedge shaped and are worked by screws; they are made of steel, with bronze bearings. At the end of each dock is a well, into which the side tunnels open, and the supply of water is regulated by sluices in the wells; these sluices are made of stout oak planks with bronze bearings working in stone grooves; they are opened and shut by hydraulic presses worked by portable pumps. These four wells communicate by a tunnel with a single large well, and this again with four other wells in which are placed the pumps, which comprise two Gwynne's centrifugal pumps, two sets of four single-acting lifting pumps, and two small pumps for drawing out water that may leak into the docks. The pumps are driven by two engines of 260 HP. each, with which one of the smaller docks, containing 4,620,000 gallons, can be emptied in three hours ten minutes, and one of the larger, containing 6,160,000 gallons, in four hours. The wells are 39 feet deep below sea-level.

The Author describes the system of construction and the order in which the works were carried out. The flooring, entrance sills, stairs and coping were of sandstone; the grooves for the caissons,

and the entrance quoins granite; the sides of the dock limestone (because sufficient sandstone could not be obtained); the tunnels and wells are brick. The hydraulic mortar is composed of equal parts of lime, sandstone and Roman pozzolana, and the concrete of 1 part of lime, 2 parts of pozzolana, and 3 of broken stone.

The works were completed in less than six years. The cost of one of the smaller docks was £65,600, without reckoning the wells or pumps. The total cost of the four docks, with pumping machinery complete, was £312,000. Drawings of the docks are appended to the Paper.

W. H. T.

Tillamook Rock Lighthouse. By Major G. L. GILLESPIE.

(Annual Report of the Lighthouse Board, United States, 1881. Appendix, p. 99, 14 pl.)

Tillamook Rock is situated in the Pacific Ocean, 1 mile seaward from Tillamook Head, and 20 miles south of the entrance to the Columbia River. It is an isolated basaltic rock, rising at one side about 120 feet above the sea, and having an area of about an acre.

In 1879 a survey was made of the rock, and it was decided to construct a lighthouse upon it, for facilitating the navigation to the Columbia River, in preference to a point on the adjacent head-land, which was difficult of access by sea or by land, and was so high as to be liable to be enveloped in fogs. Landing on the rock was difficult, and a man was drowned in attempting it. Subsequently, however, on the 21st of October 1879, two men effected a landing from a surf-boat, and secured a 4½-inch rope from the mast of a moored vessel round a high projecting ledge of rock. A block was placed on this rope capable of being hauled backwards and forwards on it, and by this means men and supplies were transferred from the vessel to the rock. The men were conveyed in a novel arrangement called a "breeches buoy," which consisted of a life-belt slung from the travelling block, to which a pair of breeches was lashed, which supported the man in the belt. Two more men were landed by this means on the 21st of October 1879, with tools, supplies and provisions; and five days later the remainder of the men were landed with a small derrick and further supplies. The nearest port in which the attendant vessel could take shelter, and from which supplies and materials had to be shipped, was Astoria, within the mouth of the Columbia River, and 30 miles from the rock.

Benches had to be formed, at high and comparatively sheltered places, on which to place a house for the men, and a foundation for the main derrick. A pathway was also formed from the landing-place to the house, and a bench was gradually carried round the rock at the 90-feet level. In January 1880 the waves were blown over the rock by the wind, and, rushing down the opposite slope, washed away the supply house and endangered the

quarters of the men. The crest of the rock was lowered, by blasting, from a height of 121 feet to a level of $91\frac{1}{2}$ feet, necessitating the removal of 4,630 cubic yards of solid rock. Particulars are given in the Report of the method of procedure and of the blasting. The levelling was completed by the end of May 1880, when a second large derrick was landed for hoisting stone and heavy materials.

Owing to the prevalence of fogs, it was essential that the light should be of the first order, and as near the sea-level as practicable.

Experience indicated that 90 feet was the lowest safe level for the buildings, and this placed the focal plane at 136 feet above sea-level. The dwelling is a stone structure 48 feet by 45 feet, and one storey high, with a building for the fog sirens, 32 feet by $28\frac{1}{2}$ feet, under the same roof. The light is placed on a stone tower, 16 feet square, rising from the centre of the main building. The tower is completed at a height of $35\frac{1}{2}$ feet from the foundations by a brick parapet 8 feet high, upon which the lantern is fixed. The light shows a white flash every five seconds. The duplicate steam sirens give blasts of five seconds' duration at intervals of one and a half minute; their boilers are supplied with rainwater collected from the roofs in a cistern capable of holding 13,000 gallons. The first stone of the lighthouse was laid in June 1880, and the lighthouse, with its light and sirens, was completed on the 8th of January 1881. The light was exhibited for the first time on 21st of January 1881.

A detailed statement of the cost is appended to the report. The total expenditure amounted to £25,375. Out of this a sum of £5,423 was expended for the use of steam tenders for the conveyance of materials; the lantern and ironwork cost £1,685, and the two steam sirens £1,056.

L. V. H.

Restoration of the Lighthouse on the Western Coast of the Bay of Kertch-Yenikal.

(Morskoy Sbornik, January 1882, Neoffitzialny otdyel, p. 167.)

This lighthouse, the rubble tower of which is 60 feet in height and 16 feet 4 inches in diameter, had been standing for sixty years, when in 1880 it began to show signs of failure. The cause was ascertained to be the unequal action of rainwater on the limestone formation under the foundations, which were not solid throughout.

Owing to the inclination assumed by the tower, the correct working of the lighting apparatus was impeded, and it became necessary to restore the structure to the perpendicular. To effect this without rebuilding, holes were bored into the ground on the other side of the tower, so as to provide, artificially, means for the water to produce the same effect here as it had previously exercised on the side that had yielded. The lighthouse then resumed a

vertical position, and the foundations, after being allowed to settle, were filled up from within, converted into a solid base, and thus permanently secured against a future occurrence of the same nature.

The work was executed in two months, though it was carried on at a most unfavourable period of the year, in January and February. The entire cost was about £90.

E. A. B. H.

The Gravity Coal-Piers at Hoboken.

(Scientific American, April 15, 1882.)

The principle upon which these piers are constructed is very simple but applied upon a large scale. The arrangement will perhaps be best understood from a description of the journey performed by each coal truck. On leaving the yard, a train of trucks, detached from its engine, runs down an incline about 1,500 feet in length to the land end of the pier, where it reaches a steep uphill incline. Each truck is here attached to a rope driven by a stationary engine and drawn up the slope. To prevent the cars from running backwards in the event of the rope breaking, inclined wooden bars are placed in the 4-foot way, so as to form a kind of straight ratchet. These inclined bars are so arranged that the front of the ascending car meets them and pushes them down. As soon as the car has passed, the bars resume their original position, and should it begin to run back, its progress would be immediately arrested by striking against the projecting ends of the bars.

On reaching the top of the incline the truck turns a vertical corner, and, released from the rope, continues its journey down a falling gradient towards the seaward end of the pier. At some point in its progress the truck is stopped by brake-power, in order to discharge its contents down a shoot into the hold of a ship standing alongside the pier. It then proceeds empty to the end of the pier, when it uses up its momentum in running up a vertical curve terminating in buffer stops. On reaching these stops the truck begins to roll back again, and, its direction being determined by a pair of points, runs down a plane (inclined in the contrary direction to that which it traversed on its outward journey) till it reaches the coal yard.

It will be seen from the above description that the pier consists of two stages, the upper, reached by a short and steep ascent, inclines down towards the sea, the lower laid in one continuous gradient from the seaward end to the shore. The upper stage is in the centre of the pier and carries two lines of rails; the lower stage is divided into two strips by the upper, and each strip carries a single line of rails.

Five of these piers have been erected in parallel lines, the whole

forming a system of wharves, docks, and basins, capable of accom-
modating about a hundred vessels.

By this system, from the time a car enters the yard loaded until
it returns to it empty, its circuit of a mile or more calls for human
intervention only where it is attached to the cable to be hauled up
the slope, and at the delivery shoot. At every other point it
moves unattended, rolling on a down grade by its own weight.
400 truck loads can be discharged per day at each pier, or 2,000
loads at the five piers, with a working force, men and engines,
that would be entirely inadequate on any other system.

The Paper is illustrated by woodcuts, which render the whole
process intelligible at a glance.

W. H. T.

The Arlberg Railway. By LUDWIG HUSS.

(Zeitschrift des österreichischen Ingenieur- und Architekten Vereins, vol. xxxiv., p. 1.)

This line, which is intended to unite the Austrian railway
system with that of Switzerland, having for terminal points
Innsbrück on the east and Bludenz on the west, will, according to
the plans adopted and now first published by the Author, be of a
total length of 137 kilometres (85 miles). The first or eastern
section of the line, 74 kilometres from Innsbrück to Landeck,
follows the Inn valley; the second, from Landeck to S. Anton,
74 to 100 kilometres, is in the valley of the Rosana, a lateral
tributary of the Inn; the third, from S. Anton to Langen, 100 to
111 kilometres, crosses the watershed between the Danube and the
Rhine by a tunnel through the Arlberg, the final descent being
made between Langen and Bludenz, 111 to 137 kilometres, in the
Klosterthal, following a stream which discharges by the Alfenz
and Ill rivers into the Lake of Constance and the Rhine. The
heights of the principal points above the sea-level are as follows :

	Feet.
Innsbrück	1,889
Landeck	2,550
S. Anton	4,272
Langen	3,992
Bludenz	1,830

The summit-level in the tunnel (4,298 feet) is 1,597 feet below
the highest point of the carriage road over the Arlberg at S.
Christof.

The geological formations encountered are, between Innsbrück
and Landeck, chiefly dolomites and limestone of the rhaetic and
triassic periods, and these continue in the mountains on the
northern side towards Bludenz, having at their base the beds of
the Werfen series and Verrucano. The summit section is mainly
gneiss and mica schist, which continue to within 15 kilometres of
Bludenz at Dalaas, where the rhaetic dolomites again appear.

The ground as a whole is tolerably free from cliff falls and slides, and good building stone is everywhere obtainable, especially in the places where it is most required.

Between Innsbrück and Landeck the maximum gradients are 1 in 113 in straight lines, and 1 in 172 in the sharpest curves, which are of 300 metres (984 feet) radius. From Landeck to Bludenz the minimum radius is 250 metres; the steepest gradient up to the summit is 1 in 38. On the western side the steeper slopes of 1 in 30·6 and 1 in 32 in straight, and 1 in 36 and 1 in 35 in curves are adopted. These correspond to average slopes of 1 in 40 on the eastern and 1 in 33·3 on the western side, which have been adopted as the ruling gradients in laying out the line.

On the summit section the road bed is laid out for a double line, the remainder is single; for this reason it is difficult to compare the estimated cost of the works with those of other mountain lines.

In many respects it will be similar to the Sillthal section of the Brenner line, but in the number and importance of the viaducts it approximates to that over the Semmering. The most important bridges are those over the Inn at Landeck, and over the Trisana brook at Wiesberg. The first requires a total length of 197 feet at a height of 60 feet above flood-level, and the second a length of 836 feet at a height of 282 feet. This the Author states to be a greater height than has been found necessary in railway bridges up till quite recently, although it is exceeded by a viaduct on the Neussarges-Marvéjols line in the department of the Loire¹ now building.

Two schemes have been proposed for the Trisana bridge: one is a single-arched lattice girder somewhat like that over the Douro at Oporto, while the second divides the interval into three spans by the use of piers of masonry 164 feet high, tapering by a parabolic curve from 37 feet broad, 24 feet at the base, to 24 feet and 14 feet 7 inches at the top. These are to be built hollow with an internal rectangular shaft 8 feet by 5 feet, so as not to require scaffolding, which will be of further use in lifting materials during the building of the main girder of 360 feet span.

The character of the works as compared with those of other mountain lines in Austria is shown in the Table (p. 378):

On the Amsteg-Göschenen section of the St. Gothard (double) line quantities per lineal metre are, excavation 63 cubic metres, dry walling 5 cubic metres, and mortar walling 10 cubic metres, and the cost per kilometre £40,300, while the steepest sections on the Arlberg line are estimated at £14,600.

The cost per kilometre of the road bed of the entire main line of the St. Gothard between Immensee and Dirinella, 147 kilometres, is £36,200, and that of the Arlberg line between Innsbrück and Bludenz, 137 kilometres, £18,000. The greater cost of the former

¹ *Vide Minutes of Proceedings Inst. C.E., vol. lxiv., p. 359.*

Objects.	Unit of Measure.	Per Metre of Line including Stations and other necessary Works.								
		Arlberg Line.						Tarnowa, Leluchow.	Divazza, Pola.	Tarvis, Pontafel.
		Innsbrück and Silz.	Silz and Landeck.	Landeck & Fierach.	Fierach & S. Autol.	Langen & Bratz.	Bratz and Bludenz.	Gryhow, and Ptaskowa.	Lupogłwa, and Borulito.	Tarvis, and Sarfritz.
Earth and rock moved, including excavation of tunnels	C.M.	16.0	30.0	47.0	26.0	56.0	14.0	48	68	23
Dry work stone and masonry	"	1.5	5.6	6.6	0.9	4.8	1.5	0.5	0.3	3.3
Mortar masonry, including lining of tunnels . . .	"	0.25	0.6	3.4	1.2	6.6	0.6	1.4	1.1	5.6

is in part due to the use of curved tunnels which might, as regards the trace, have been advantageously used on the western side of the Arlberg but for their much greater expense. The expenditure will also be kept down by the systematic use of undressed stone with hydraulic mortar in work of all kinds, including arches up to 60 metres span.

The entire building cost of the section Innsbrück to Landeck is estimated at £800,000, and that of the Landeck-Bludenz at £2,760,000.

The strength of the bridges, which are to be of mild Bessemer steel, is calculated for heavy goods trains drawn by three eight-coupled engines, by Weyrauch's formula.¹

The plan of the tunnel through the Arlberg having been previously described by Herr Plate, the Author only gives some details as to the progress of the works, giving as points of special interest the method of keeping the bottom drift in advance, the general use of rough instead of dressed stone for the masonry lining, and the concentration of the works over a comparatively short section so as to keep the finished work and the advanced drift as near together as possible.

In the second half of October 1881 the advance of the eastern end at the rate of 500 feet per month, and that of the walling 433 feet, the bottom drift having progressed at the rate of 13 feet 9 inches per day. On the west side, where the rock was not so favourable to the miners, the figures were, excavation 328 feet, walling 240 feet, and the average length driven daily 10 feet. The drifts on either side were of the same length, namely, 754 yards. The complete excavation and walling is done in annular sections, which are of the average length of 27 feet on the

¹ Vide Zeits. österr. Ing. Architect. Verein, 1880, pp. 101, 102.

west, and 23 feet on the east side. The first operation requires about twenty-one days per ring on either side, while the walling of the same length is finished on the east side in fourteen, and on the west in twenty-one days, from ten to twelve sections being in work at the same time. The concentration of the working force within a section of 600 to 700 metres (656 to 765 yards) is a condition of the contract, having for its objects the simplification of the ventilation, and to ensure the rapid completion of the work after the drifts have been joined, the time specified for this being six and a half months. The completion of 4 metres (13 feet $1\frac{1}{2}$ inch) of full-size tunnel in each end daily necessitates the removal of about 240 cubic metres (313 cubic yards) of rock, besides blunted tools and machinery requiring repairs, and the introduction of about 78 cubic yards of stone, 20 cubic yards of sand, 5 tons of hydraulic lime, and large quantities of tools, explosives, timbers, &c. The actual amount moved is from 650 to 700 tons outwards, and 200 to 300 tons inwards at either end, a very considerable amount of work to be done by a line of 27 $\frac{1}{2}$ inches width of gauge. The walling is almost entirely carried out with undressed stone, dressed blocks being only used to the extent of about one-third on the west side, and it is hoped that the nature of the ground will soon permit the use of these to be discontinued.

H. B.

NOTE.—The following additional particulars relative to the tunnel are given in a Paper by Herr G. Plate in vol. xxxiii. of the same "Zeitschrift," p. 25. The tunnel will be 10,270 metres (6 $\frac{1}{2}$ miles) long. Gradients from the highest point, which is 4,205 metres (4,598 yards) from the eastern end, are 1 in 500 eastward and 1 in 66 westward. On the eastern side the boring is done by percussive machines similar to those used in the St. Gothard works. Of the three systems, those of Ferroux, Seguin, and Welker, that have been tried, the latter seems to be the best suited for the work. This power is furnished by two pairs of double-acting wet compressors, each pair driven direct by a Girard turbine with 57 feet fall. The supply of water varies with the time of year when, at a maximum, it is equal to about 225 HP. gross.

On the west side Brandt's hydraulic borer is used, the necessary hydraulic pressure being got by an accumulator loaded to 100 atmospheres, which is fed by pumps driven by a Girard turbine with a fall of 80 metres, equal to 150 HP.

When the works are fully developed there will be six additional compressors driven by water-pressure engines pumping 150 cubic metres (5,300 cubic feet) per minute at six atmospheres pressure for power, and four more for ventilation, giving 180 cubic metres (6,357 cubic feet) of air per minute on the east side. On the west side two additional groups of four pressure pumps are to be added for power, and six centrifugal blowing machines for ventilation.

In the "Eisenbahn," vol. xvi., p. 79, further details as to the section, methods of lining, and contract price of the tunnel works, are given. At the end of February 1882, the total length driven was 2,168 metres on the eastern, and 1,638.5 metres on the western side. The average daily advance for the year 1881 was 3.88 metres on the eastern, and 4.75 metres on the western side. The highest single day's work was 6.80 metres. The arrangements for conveying water to the works are of a very extensive nature. On the eastern side the necessary power is taken from the Rosana by two leats. The first, intended for provisional use, takes the water about 1,000 metres from the tunnel mouth, has a fall of 17.5 metres, and 150-240 HP., according to the time of year. The second supply is taken 4500 metres from, and 140 metres above, the working place. At both

there are weirs across the Rosana, and the water is carried in wooden launders, of 0·8 square metre section, with a fall of 1 in 500. The longer one ends in a reservoir lined with masonry, whence a pipe, of 900 millimetres diameter and 510 metres long, conveys the water to the engines. The pipe is made of Bessemer steel plates, 7 to 11 millimetres thick, double riveted, costing £7 6s. per lineal metre. It has a fall of 132 metres, and gives, according to the state of the river, from 930 to 1,700 HP. The long open leats are liable to become obstructed, especially in winter, and, to keep them clear, watchhouses have been erected at intervals along their course, which are placed in telegraphic and telephonic communication with each other. On the western side at Langen the conditions are less favourable, the gathering ground of the Alfenz being comparatively restricted. The water is taken at two points, having 85 and 150 metres fall respectively, giving from 130 to 500 HP. The conduit is a sheet-iron pipe, of 500 millimetres diameter, and 2,900 metres long, which, for the greater part of its length, is laid along the high road. At the higher end a walled reservoir has been established at the hamlet of Stuben, for equalising the supply in dry weather. A second leat takes water from the Alfenz, about 50 metres above the tunnel mouth, and delivers with a head of 90 metres to a lower engine-house 40 metres below and 500 metres from the tunnel. This gives, as a minimum, 150 HP.

The estimated cost of the tunnel, including the road bed, is £1,355,550, or £132 per metre, taking the whole at the nominal value of 2s. per florin, which is however about 17 per cent. too high at present rates of exchange.—H. B.

Report upon Permanent Way laid with the Vignoles Rail as compared with the double-headed Rail.

By — VICAIRE.

(Annales des Mines, vol. iv. of 1881, p. 5.)

The inquiry as to the respective merits of these two types of way was undertaken at the recommendation of the Council of the "Ponts et Chaussées," which appointed, through the Minister of Public Works, a committee of technical men to draw up a series of questions, to be forwarded to the various railway authorities in France, and to consider and report upon their replies.

This report treated the subject under the following heads, viz., cost of construction, expense of maintenance and renewals, and general remarks as to advantages peculiar to either system.

Cost of construction.—The item of ballast is not affected by the type of way adopted excepting that in the chair-road the average amount is increased by a layer of about 2 inches thick above the sleepers, which is equal to a cube of 0·30 to 0·37 cubic yard per lineal yard for a single line, or 0·55 to 0·60 cubic yard per lineal yard for a double line. This additional amount of ballast is useful as a protection to the sleepers,¹ besides giving extra stability to the road.

¹ At the eighth meeting of the German Railway Engineers Association held at Stuttgart, 1878, twenty-seven authorities were in favour of keeping the sleepers covered, and only seven to the contrary.

A Table is given showing details of the cost of rails, fastenings, sleepers, &c., for various railways laid with the double-headed rail, both in iron and steel, and similar information with regard to the Vignoles rail (including the Austrian State Railway), from which is compiled a Table immediately comparing the cost of the various items. That of fastenings (including chairs) for the double-headed way varies from £207 16s. to £322 12s. per mile, and for the Vignoles road from £26 to £68 3s. per mile, or an average of £234 5s. per mile for eight roads of double-headed way, and £46 9s. per mile for thirteen lines laid with the Vignoles rail. The average weights of the double-headed rail in iron and steel respectively, are 74 and 77 lbs. per yard, and those of the Vignoles rail are 71 and 65 lbs. per yard.

Another Table gives the weights and prices per kilometre of chairs in use on various French railways, also of the London, Chatham, and Dover Railway, followed by one giving the weights and prices of bed-plates (Selles) used with the Vignoles rail upon many lines (these are referred to again under the head of "Maintenance"). The difference in price between the two types of way (as far as concerns attachments of rail to sleeper) varies ordinarily from £161 to £257 12s. per mile (2,500 francs to 4,000 francs per kilometre) according as to whether bed-plates are used with the Vignoles rail or not.

As regards sleepers, the differences between the averages of the two types is slight, the prices being £409 10s. and £412 3s. per mile, the latter for the Vignoles.

The average number of sleepers for the Vignoles is 5 per cent. more than for the double-headed rail. This excess is due to various causes, the principal one being the smaller bearing surface of the rail upon each sleeper.

A Table is given showing the sectional areas and the moments of resistance to rupture and lateral flexure, of the principal sections of rails in use in France, from which it appears that the double-headed rails there instanced possess less flexibility and greater resistance to rupture than the Vignoles, but this is due to the larger sectional area of the former. The comparative resistance to rupture of a double-headed and Vignoles rail of equal sectional area is decidedly in favour of the latter. After the Vignoles form of rail (in iron) had been adopted by the Paris, Lyons, and Mediterranean Railway Company it was found that the number of broken rails was reduced to seven-eighths of what it had been with the double-headed rail.¹

Experiments made in Germany during the past thirty years have led to the acknowledgment of the superiority of the Vignoles rail as regards resistance to rupture, but a slight inferiority as regards resistance to permanent deformation.

¹ "Rupture of Rails, &c.," by M. Couard (*Revue générale des Chemins de fer*, August, 1880).

A Table of trial tests for newly manufactured rails, adopted by various companies, is given, which shows results in favour of the Vignoles rail.

The comparative cost of a kilometre of line laid with the double-headed rail (77 lbs. per yard), and the Vignoles heavy (77 lbs. per yard) and light (61 lbs. per yard) rail, based upon prices common to all three, is given.

Maintenance.—In the maintenance of these ways the supervision is easier in the case of the chair-roads, as the keys are readily tightened and the sleeper attachments inspected without disturbing the ballast, but the inspection requires to be more frequently made than in the Vignoles road, and consequently the expense under this head is greater for the chair-road, at the same time the latter type possesses an advantage in the facility with which a rail may be changed, the time varying from five to ten minutes, whereas the Vignoles rail requires twice as long, but this is not considered to be of much importance, excepting in the case of lines where the trains follow in extraordinarily quick succession, as on the London Metropolitan.

The Northern and Eastern Railways of France, and almost the whole of the German lines have adopted the Vignoles rail.

An account is furnished of the number of rails discarded before or after reversal during the twenty years previous to 1878 on the Paris and Havre Railway.

Although the reversal of rails is useful in cases where the one head may be defective in manufacture, and undoubtedly was a question of considerable importance before iron had been practically superseded by steel, and when the life of a rail was limited to ten or twelve years (now probably increased to forty or fifty) the advantage to be derived from reversal is diminished with the increased length of time likely to elapse before its being called into service, together with the possibility of radical changes in view as regards permanent way occurring in the meanwhile.

What is recommended for a chair-road is, that after deciding upon the best section of rail for resisting strain, viz., that in which the amount of metal would be equal in both heads, but the lower one splayed and so shaped as to sit firmly in the chair, a slight amount of excess of metal, say $2\frac{3}{8}$ inches broad and $\frac{3}{8}$ inch thick (about 9 lbs. per yard, $4\frac{1}{2}$ kilograms per lineal metre) should be added to the top table to make up for wear and tear.

The life of the sleepers in the case of the Vignoles road is shortened by the use of fang bolts and the tendency of the foot of the rail to cut into the sleeper, especially on the outer edge in sharp curves, but this objection may be got rid of to a great extent by the use of hard timber. Even with the chair-road, when the base area of the chair is small and the timber soft, it is found that the sleepers are injured by crushing.

The wear and tear of sleepers is reduced to a minimum with a broad based chair and when kept covered with ballast.

General remarks.—As regards the security of permanent way, the

principal conditions are preservation of the gauge, elevation of the outer rail on curves and the condition of the rail joints.

In the Vignoles road, especially where soft wood sleepers are used, there is a difficulty in preserving the gauge, owing to the horizontal action of the wheel tires tending to spread the rails, and to enlarge the holes through which the fang-bolts pass.

In both types of way the suspended fish-plate joint is now generally adopted, but the Vignoles as compared with the double-headed way of equal weight, allows of a deeper and, consequently, stiffer fish-plate (a Table of fish-plate depths on various systems is given), and the former type of rail is better adapted for resisting lateral pressure. The Vignoles rail, however, from its narrow base, offers less resistance to overturning than the chair-rail, which although greater in height is more than compensated for in that respect by the width of the chair-base and the distance apart of the attachments to the sleepers, consequently in the former type the tendency (upon curves) to draw the fastenings upon the inner side of the rail and bury the outer edge of the rail foot into the sleeper is greater. The experiences of various companies regarding this tendency are given.

The Northern and Eastern Companies have on this account increased the diameter of their fang-bolts from $\frac{3}{4}$ inch to $\frac{7}{8}$ inch (full).

The Vignoles road may therefore be considered as superior in point of rigidity of rail and joints, but inferior as regards preservation of gauge. The latter defect may however be overcome by employing fang-bolts of extra strength and iron bed-plates through which the attachments pass, of sufficient area between the sleeper and the foot of the rail, and the Vignoles road will then be placed on an equal footing with the chair-road in this respect, and, at the same time, be far more economical in construction.

The commission came to the following conclusions:—

1st. That there does not exist any absolute reason for giving a preference to the chair over the Vignoles way, as both types afford satisfactory results in all cases where the rails are of suitable weight, the sleepers sufficient in number, well ballasted, and properly maintained.

2nd. That the employment of chairs having ceased to be, for the purpose of the prolongation of the service of rails, by reversing (an operation no longer worthy of being taken into calculation in the case of steel rails), the rail section may be such as is best suited for resistance to strain, accompanied by an increased depth of table to compensate for wear.

3rd. That as regards the choice of the type of road for new lines by the State, the advantages sought for by the adoption of a new special type of rail will not be commensurate with the inconvenience that might result to the companies called upon to work these lines, that it would therefore be advisable to adopt the type of road already in use on the main lines, to which those in question are to be feeders, unless too expensive, in which case,

rather than experiment, it would be preferable to adopt some less costly road already in use elsewhere.

An appendix of additional information regarding improvements in construction, &c., elicited during the inquiry is given, including the relative merits of hard and soft steel, the general dimensions and weights of rail-sections in use in France, also of fang-bolts, dimensions of fish-plate sections and sleepers, also the preservation of timber with sulphate of copper, creosote, and by charring.

D. G.

Abt's Combined Locomotive- and Rope-Traction-Incline Railway.

(Zeitschrift des Vereines deutscher Ingenieure, 1882, p. 27).

By this system ordinary locomotives are enabled to overcome the difficulty of ascending or descending inclines of not more than 1 in 8·5 of steepness; thus dispensing with the use of toothed geared locomotives, or rope traction, which have a very limited use and require a large outlay of capital, especially where at both ends of the incline ordinary locomotives are used to carry on the traffic, and where two locomotives are perhaps required when one would suffice, if it could traverse the whole distance.

To surmount the difficulty of an incline of 1 in 8·5, in an otherwise easy railway, without adopting the expensive method of cutting levels, a rope is laid on rollers between the rails, one end of which is fastened to the engine, while the other end, passing round a pulley at the top of the incline, is fastened to a train of vehicles sufficiently loaded to counterbalance the weight of the locomotive and the tare of the load.

This counterbalance descends the incline on the same line of rails, a passing-place being provided at mid-distance. The passing of the counterbalance into the loop and from it again is automatic, and is accomplished by outside flanges on the wheels, or by making one side of the counterbalance wheels with double flanges, leaving the other side wheels without them, or making the ordinary inner flanges of great depth in order to be caught in grooves which the ordinary flange would pass over. An ordinary locomotive weighing 12 tons can in this way ascend an incline of 1 in 8·5 with a load of 18 tons at a speed of $7\frac{1}{2}$ miles an hour. For inclines above 1 in 8·5, and not exceeding 1 in 2, Abt's system, combined with tooth-geared locomotives, could move a load of 10 tons as readily as the tooth-geared engine of the Rigi does a similar load on 1 in 4.

The system is at work on two railways at present, one in Switzerland and the other in Saxony.

C. Z. B.

The Como-Fino-Saronno Steam-Tramway. By RODRIGUEZ FELIX.

(Il Politecnico, January-February 1882, p. 5.)

This tramway, with the exception of a short piece in the suburbs of Como, then nearly finished, was opened for traffic in October 1880. In reference to the danger to horse traffic, the Author states that this is obviated by the use of the whistle. The rapid passage of a train, if unexpected, frightens horses; but if the whistle is sounded the drivers can always keep their horses under control. The whistle has however been given up, and bells substituted, which are by no means so effective, the sound not being sufficiently distinguishable from that of the moving-train.

The total length of the line is about $14\frac{1}{2}$ miles, of which about 1,200 yards are laid along streets, 980 yards in suburbs, $4\frac{1}{2}$ miles along provincial roads, and 9 miles on ground acquired for the purpose. The population of Como is 24,400, that of Saronno 7,000. There are thirty-four towns and villages, with populations varying from 500 to 4,000, either upon the line or within 3 miles of the nearest station on it. The speed of the trains is limited to 20 or 25 miles per hour. The sharpest curves are 650-foot radius, except in towns, where the speed is limited, and curves of 325 feet are allowed. The steepest gradient is 1 in 19. As the line forms a junction with a railway it had to be made on the 4 feet $8\frac{1}{2}$ -inches gauge. Formation width (except upon roads) is 13 feet (not including the side ditches), which is increased to 16 feet 6 inches upon high banks. On the provincial road the formation coincides with the bottom width of the ballast, and is 11 feet. On roads the tramway is generally laid along the side, the road surface being the formation; but when the tramway encroaches upon the part of the road used for ordinary traffic the rails are laid level with the road surface; in the former case, a width of from 16 feet 6 inches to 19 feet 8 inches is reserved for the ordinary traffic. In some places the tramway is laid on a bench formed upon the slope of the road. The width of bridges and culverts is 9 feet 10 inches.

The ballast is 1 foot 2 inches thick, 8 feet 6 inches wide on the top and 11 feet 6 inches at the bottom, giving $1\frac{1}{2}$ cubic yard per lineal yard. The sleepers are of oak, 7 feet 6 inches long, $6\frac{1}{4}$ inches wide, and $4\frac{1}{2}$ inches thick, except the joint sleepers, which are 7 feet 6 inches by 7 inches by $4\frac{1}{2}$ inches. The rails are Vignoles' pattern, of Bessemer steel, weighing 46 lbs. per yard. Where the tramway is in the middle of the road guard rails are laid, leaving a space of $1\frac{1}{2}$ inch on straight lines and $1\frac{3}{4}$ inch on curves, for the wheel flanges to run in. In towns the roads are paved. The angle adopted for crossings is $8^{\circ} 31' 50''$, the tangent of which is 0.15; the curves are 262-foot radius, and the length of straight about 10 feet, the wheel-base of the engines being 6 feet 6 inches.

The buildings at Como consist of a passenger station, shed for two locomotives, a carriage shelter, and a goods shed, with loading

platform, the whole covering an area of 7,535 square feet. At Saronno the existing railway station is to be used for passengers; sheds for five locomotives and eighteen carriages, a repairing shop, a coal store and two offices, are to be built, and also a rain-water tank to hold 44,000 gallons; the water being required for washing the carriages, and as a protection against fire. The area to be covered is 12,916 square feet.

There are ten intermediate stopping places, of which, at present, three have from 110 to 220 yards of double line. At one a station has been built, at the others rooms are hired, or tickets are sold at inns and cafés. Platforms are provided at all but one, where wooden stairs are used for giving access to the carriages. Hand signals are used at the intermediate stations, but at Como and Saronno fixed signals are provided.

When the tramway is on the side of the road it is in some places fenced off with a hedge of white thorn; in other places the elevation of the ballast above the road surface forms a sort of fence, which is supplemented by upright stones fixed at intervals of 16 or 17 feet, to separate the tram from the cart road. Public road level crossings are protected by bars or chains, but occupation crossings are not.

The rolling stock consists of five locomotives, twenty passenger carriages, and four platform cars. Two more locomotives, five carriages, four goods wagons, and two luggage vans, are to be provided. The engines are six-wheel coupled, working to a pressure of 9 atmospheres; they will readily run round curves of 260-feet radius, and will take loads of 35 tons up the steepest gradient on the line. All the carriages have a wheel-base of 9 feet 10 inches, and are fitted with Klotz's system of radiating axles. All the wheels have brakes worked by levers or screws, and the engines are fitted with counter-pressure brakes.

The total cost of the line was £4,617 per mile, of which £3,488 was for construction (including the purchase of land where required), and £1,130 for equipment.

W. H. T.

Competition of Tramway Engines at Arnheim.

(Organ für die Fortschritte des Eisenbahnwesens, 1882, p. 7.)

The Dutch steam tramways have now a length of 90 miles actually open, and 180 miles under concession. These are mostly of 4 feet 8½ inches gauge, and have light steel Vignoles rails on wooden cross-sleepers, though some recent types of iron sleepers are in use. The cost of the permanent way has averaged about £1,600 per mile.

The choice of tramway engines for these lines is a matter of great importance. For such purposes simplicity and economy go hand-in-hand, and all burdens and complications should, if

possible, be dispensed with, such as condensers, closing in of the mechanism, and complicated machinery, or arrangements of all sorts. A tramway engine, even in towns, need be distinguished from a small well-built tank locomotive by nothing except being smokeless, and this can be sufficiently attained by the simple use of coke.

The Arnheim Tramway Company lately arranged an open competition for tramway engines, to be decided by a committee of five members, under the presidency of Heer Stous-Sloot, Locomotive Superintendent of the Netherland State Railways. The conditions were as follows:—(1) The engine to be brought to the spot and removed at the maker's cost; (2) to have a trial of at least fourteen days; (3) to conform to the Dutch laws on boilers, be of normal gauge, and be able to condense the steam on a trip of $1\frac{1}{2}$ mile; (4) to be fired with coke; (5) fuel, &c., to be supplied by the Company, wages, &c., by the maker. The firms which competed were Merryweather's, of London; the Hohenzollern Locomotive Company, of Dusseldorf; the Swiss Locomotive Company, of Winterthur; and Krauss & Co., of Munich. The trial-track was about 3,000 yards long. The steepest gradient was 1 in 88, and the smallest radius of curve 22 yards. Each engine had for fourteen successive days to run the regular trip in turn with the horses, whilst the engineers made careful observations on the expenditure of fuel, oil, and water, the atmospheric conditions, brake-action, condensation of steam, &c. Afterwards an official trial was made with a train-load of 10 tons, which was hauled over about 30 miles.

The prize was won by the Krauss engine, which expended in the trial-run about 370 lbs. of coke, including firing up, and 3·6 lbs. of oil. This engine was the simplest of all in construction, and had the best condenser, which consisted of one hundred and thirty copper pipes arranged transversely on the roofs, each 1·6 inch internal diameter, and 0·04 inch in thickness. The exhaust steam passes into these pipes from a box cooled by the feed-water, and any steam not condensed in the pipes is led into a tank of condensing water.

A special feature of the Krauss engine is that the frames are made in a box shape, and form the feed-water tank. This gives the three following advantages:—(1) It forms the strongest possible base-plate for the engine and boiler; (2) it saves weight, from the absence of the tank and stronger form of the frames; (3) the centre of gravity is lower, which is of great importance on lines so irregular as tramways often are.

The boiler is quite separate from the frames, and is of the simplest locomotive construction. There is no steam dome, but the steam is taken from a collecting pipe, and is quite dry. The barrel of the boiler is of steel, the outer fire-box shell of iron, and the fire-box of copper.

The valve motion is the ordinary Stephenson link; the engine rests on two longitudinal springs above the driving-axle, and a

water throughout, the gas being made on the premises. There are $7\frac{1}{2}$ miles of railway laid down in the sidings and workshops. The east and west position of the lines of rail has enabled the shops to be lighted by north light through the roof; the roofs consist of parallel ridge roofs carried on lines of columns, the ridge is, in each case, out of the centre of the span, and the steep side is covered by a continuous skylight. The most noteworthy shop is the locomotive repairing-shop; this contains twenty-seven pits, each for two locomotives; the pits are arranged on each side of a central traverser; this arrangement saves space, but has the apparent disadvantage, that the locomotive next the wall is shut off from the traverser by the one in front; it is, however, found in practice that a little judgment in arranging the work gets over this difficulty. The locomotive pits are spanned by portable gantries, which run on the floor; these are worked by hand, and lift loads up to 20 tons; lifting-beams, worked by a screw-jack at each end, are also used. The repairing- and boiler-shops are furnished with a very complete system of light portable rope gearing, driving from pulleys on the shafting; by this means stays can be drilled out, cylinder-ends faced up, and a great deal of other work done, in any position, on a boiler or locomotive. The Paper contains full particulars of this system, and details of the method of driving and taking-up the slack of the rope, and also illustrations of some of the portable machines employed. Besides the ordinary large turntables, there are, in various parts of the lines, small turntables for turning a single axle and pair of wheels; these consist of a bar pivoted at the centre and carrying a shoe at each end, on which the wheel rests. For small trolleys turntables about 6 feet 7 inches in diameter are used; these are made of cast iron, and in very few parts; the top table is cast in a piece with the rails, and has on its underside a semi-circular groove which drops over steel balls running in a similar groove in the base casting; a ring with holes in it keeps the balls in pitch.

The Paper is illustrated by five plates.

W. P.

The Wenger Continuous Brake. By T. HIRSCH.

(Portfeuille économique des Machines de l'Outillage, vol. vii., p. 50, 1882.)

The new compressed-air brake invented by M. Wenger was fitted in October 1881 to a train belonging to the Orleans Railway Company, and running between Paris and Orleans. The brake has been in use on this train ever since, and is giving satisfactory results.

The Author describes the brake as fitted to the experimental train, and then the important simplifications and improvements introduced since by the inventor. The apparatus, as originally

fitted, consists of a compression-pump and reservoir on the engine, brake-cylinders under the vehicles, two conducting-pipes, a regulator under control of the driver, and sundry valves. Each brake-cylinder actuates two sets of brakes by pulling on two piston rods, passing one through each cylinder cover. Two main pistons on these rods divide the cylinder into two end divisions A A, and a middle division B; two smaller pistons fixed to the rods work in short tubes cast on the cylinder-covers. The four pistons are packed by leathers so turned as to retain the pressure in A A. Air under pressure is constantly supplied to A A through a non-return valve by one of the pipes. The pressure in B is controlled by the second pipe. Should this pressure fall below that in A A, the large pistons overcome the small ones, the rods are drawn inwards and the brake is applied with any desired degree of force. If the pressure in B is made the same as that in A the large pistons are placed in equilibrium, the small pistons thrust the rods outwards, and the brake is taken off. The escape-valve, which regulates the pressure in B, consists of a small cylinder communicating with the atmosphere by a hole through one end. Generally this hole is kept closed by the leather face of a piston being forced against it by pressure on the back. The back of the piston is in connection with the controlling-pipe, and the front communicates with B. There is a small hole through the piston, by means of which the pressure in B is kept equal to that in the pipe; should, however, the pressure in the latter be suddenly lowered the piston rises and B exhausts into the atmosphere. The regulator on the engine consists of a small valve-box supplied with air from the reservoir, and also in direct communication with the pressure-pipe leading to A A. In the valve-box is a small D valve, by means of which the pipe to B can be supplied with compressed air more or less wire-drawn, or placed in connection with the atmosphere. The valve-rod carries a piston, one side of which has the full pressure, resisted on the other side by an adjustable spiral spring, and also by the pressure obtaining in the controlling pipe leading to B. These opposing forces tend automatically to establish equilibrium, for if the pressure on the spring be increased the valve gives more exhaust and less pressure in the controlling pipe. By following the connection link by link it is seen that, apart from friction, the pressure applied to the brake blocks is proportional to the pressure on the handle which regulates the spiral spring. The driver is thus completely master of his brake, and feels by his hand the intensity of the action he produces. There is a supplementary cock by which, in time of danger, the controlling-pipe can be discharged into the air. Similar cocks can, if necessary, be opened from any vehicle.

Tables are given of the stops made at the private and official trials on the Orleans Railway. The following are the best results obtained on the 17th of November, 1881, when the weather was damp and the rails greasy. The figures refer to a level line, the correction for gradient having been made where necessary.

Station.	Speed.	Pressure.	Distance Stopped in
	Kil. per Hour.	Atmospheres.	Metres.
Choisy-le-Roi	68	6½	162
Ablon	75	6½	182
Épinay	60	6½	140
Perray Vacluse . . .	40	6½	99

Since the brake was brought out a great simplification has been introduced by the entire suppression of the pressure-pipe leading to A A. It is found that these spaces keep themselves charged from B by means of the piston leathers, which, though perfectly tight against pressure from A to B, readily admit air from B to A, and thus form self-acting valves. The same principle is also applied to the escape valve, whose piston is packed with a leather which admits pressure to B and replaces the small hole mentioned above. The brake can be readily coupled up in the same train, and to the same pipe, as the Westinghouse brake, and the two worked together. The Author remarks in conclusion that the brake is simple, durable, and powerful. It acts as an ordinary or danger brake; it acts simultaneously on all the vehicles, is automatic, and the pressure on the brake-blocks can be regulated; and, in view of the conclusive experiments made with it on the Orleans Railway, he considers it very desirable that the Wenger brake should be tried on a large scale.

W. P.

The Most Economical Point of Cut-off in Steam-Engines.

By A. R. WOLFF and J. E. DENTON.

(Transactions of the American Society of Mechanical Engineers, May 1881.)

The key-note of the enquiry into the most economical point of cut-off in steam-engines was marked by Professor Rankine, who stated in 1854 that, whilst increasing the ratio of expansion in Cornish engines, the quantity of steam required to perform a given duty is diminished, and the cost for fuel and boilers is lowered, the cost of the engine is at the same time increased, as it must be enlarged. The case is one of maxima and minima, to determine the ratio of expansion which is on the whole most conducive to economy in capital outlay and current expenses compared with the work done. It is deduced by the Authors that the most economical point of cut-off is not materially affected by slight variations of any of the quantities which enter into the problem, although empirical formulas have been employed which, in many cases, gave results differing widely from the true measures.

A graphical method of solution is illustrated by a large diagram, in which the base-line is made to measure the capacity of the steam-cylinder, and is divided into a number of equal parts by vertical ordinates numbered consecutively from zero. The total length of the base being divided by an intermediate length, the quotient is the ratio of expansion due to the cutting-off of the steam at the end of the intermediate length. Two curves are traced on the diagram, showing the relative absolute average pressures of steam due to each ratio of expansion, one of these curves being that due to Mariotte's law of expansion, and the other that due to the adiabatic law of expansion. A parallel to the base-line is drawn, measuring back-pressure and frictional resistance. To find the most economical point, four values, designated respectively A, B, C, and D, are ascertained for each case. A, the "cost of full steam," consists of the cost of steam used per hour, when admitted for the full stroke, including allowance for condensation; the wages of firemen per hour; the interest on the cost of boilers per hour; the depreciation in value of the boilers per hour; and the cost for repairs of the boilers per hour. B, the "cost of engine," consists of interest on the cost of the engine per hour; depreciation in the value of the engine per hour; cost for repair of the engine per hour; cost for oil and waste per hour; and the wages of the engineer per hour. C is the quotient obtained by dividing the constant 16.44, employed to represent the whole length of the cylinder, by the value A; and D is the quotient obtained by dividing the sum of the back pressure and the friction of the engine in lbs. per square inch by the initial absolute pressure of the steam. The value C is set off on the base-line from the zero point to the left, the capacity of the cylinder being laid off to the right. Drawing an ordinate from the extremity of the value C thus set off, the value D is set off on the ordinate, and fixes the position of a point from which a tangent is to be drawn to the adiabatic curve. A vertical ordinate drawn through the point of contact of the tangent with the curve marks the point of cut-off and the ratio of expansion of greatest economy. An elaborate general analysis is given, together with examples and appendices; but the rationale of the diagram is wanting, and it does not appear that the clearance at each end of the cylinder enters into the calculations.

D. K. C.

Experiments on Waste of Steam in the Steam-Engine.

By Prof. R. ESCHER.

(Civilingenieur, 1881, p. 519.)

The Author made experiments to determine the loss by condensation on the sides of the cylinder. For this purpose an apparatus was made, which consisted of two cast-iron plates separated by a

ring of brass wire, and bolted together so as to leave a thin disk-shaped space between them: two ports furnished with slide-valves opened into the space so that it could be alternately connected with admission- and exhaust-pipes, under similar conditions to the interior of a cylinder. The slide-valves were driven by an eccentric whose speed could be varied at pleasure. Care was taken to supply dry steam to the admission-valve. The exhaust port communicated with a condensing-coil from which the whole of the steam used could be obtained as water and weighed; the difference between this weight and the theoretical weight due to the volume of admitted steam gives the condensation during admission. The coil could be connected with an air-pump or worked at atmospheric pressure, and the plates could be steam-jacketed at will.

The condensation was found to be the same with or without the air-pump. The results are expressed by the following formulæ:—

g = weight in grams of water condensed per square metre of surface at each admission;

τ = duration of admission in seconds;

p = admission pressure of steam in atmospheres.

$$g = 32.56 \, p^{0.413} \tau^{0.44} \quad . \quad . \quad . \quad . \quad . \quad \text{without jacket;}$$

$$g = 5.384 \, p^{0.323} \tau^{0.46} \quad . \quad . \quad . \quad . \quad . \quad \text{with jacket.}$$

For example, for $\tau \approx 0.1$ second $p \approx 6$ atmospheres and un-jacketed plates the water condensed was $g = 15.633$ grams per square metre (0.0105 lb. per square foot). The Author states that this result is about six times as great as that usually reckoned for a surface-condenser.

The second series of experiments was made with the experimental condensing-engine belonging to the Zürich Polytechnic, the object was to determine the loss by piston-leakage. The cylinder was 300 millimetres in diameter (11.8 inches) and of 750 millimetres length of stroke (29.53 inches). Owing to the want of a sufficiently powerful friction-brake the steam had to be cut off very early in the stroke. The experiments showed that for a pressure of 5.5 atmospheres cut off at $\frac{1}{6}$ of the stroke, and a speed of 67.3 revolutions per minute, the loss was 1.762 gram (0.062 lb.) per stroke when unjacketed, and about 1.054 gram (0.037 lb.) when jacketed; in the latter case the revolutions were 72.2 per minute.

The Author calculated the theoretical weight of admitted steam, allowing for 10 per cent. super-saturation, and added to this the amount lost by surface-condensation and piston-leakage, as determined by the experiments, but the result was still 30 per cent. less than the steam actually used, from which the Author considers that the real condensation in a cylinder greatly exceeds that given by his experimental apparatus.

W. P.

On the Determination of the Principal Points of an Indicator Diagram. By Prof. A. FLIEGNER.

(Die Eisenbahn, 1882, vol. xvi., p. 26.)

In the calorimetric investigation of a steam-engine it is important to determine as exactly as possible the end points, on the diagram, of the expansion- and compression-curves. In many cases there is some difficulty in doing this with sufficient accuracy, and the Author proposes, therefore, to plot on the diagram another curve which is more sensitive to an alteration of the volume behind the piston. The curve used is that which represents the amount of dry saturated steam in a weight unit of the mixture of steam and water in the cylinder at any given moment (*die Curve der specifischen Dampfmenge*).

Let F represent the area of the piston.

- „ s „ the distance travelled by the piston from the beginning of the stroke.
- „ s_0 „ the length of the clearance spaces when reduced to the area F .
- „ G „ the weight of mixed steam and water admitted per stroke.
- „ G_0 „ the weight of mixture remaining in the clearances at the beginning of the stroke.
- „ x „ the specific quantity of dry saturated steam at any moment (*i.e.*, the weight of dry steam in a weight unit of the mixture).
- „ v „ the specific volume of dry steam due to the pressure at that moment.
- „ σ „ the specific volume of water.
- „ $u = v - \sigma$.

The volume behind the piston at any moment will be

$$\text{and} \quad \begin{aligned} (G + G_0)(xu + \sigma) &= F(s + s_0) \text{ during expansion,} \\ G_0(xu + \sigma) &= F(s + s_0) \text{ during compression.} \end{aligned}$$

All the quantities necessary for the calculation of x from these equations can be obtained from the diagram except G_0 , and by adopting the usual hypothesis, that at the end of compression the clearances are filled with dry saturated steam (in other words, that $x = 1$ at this moment), G_0 can be found, and consequently x . During expansion and compression $G + G_0$ remains constant; if now the plotting of the curve for x be continued beyond the proper limit of expansion or compression, still retaining the constant value of $G + G_0$, quick turns in the curve will result, and these show the required points.

The Author gives an example worked out on the diagrams of a compound engine; in these the true point of cut off is sharply defined by the x curve, although the expansion curve shows considerable wire-drawing.

W. P.

On Slide-Valve Distribution. By PHILLIPPE BANNEUX.

(Annales des Travaux Publics de Belgique, vol. xxxviii., 1881, p. 249.)

In this Paper the Author gives a very exhaustive analysis of the methods of treating the various geometrical questions that arise in connection with the slide-valve. The Author first describes the different diagrams which have been used or proposed (amongst others those of Müller, Reuleaux, and Zeuner), the approximate valve-ellipse and line of sines, and the allied curves which replace the two last, when the obliquities of the connecting and eccentric rods are taken into consideration.

The second part of the Paper deals at great length with Zeuner's polar diagram. The Author proposes and analyses simple methods, by which not only the positions of the valve and piston but also the velocities and accelerations and the corrections for the lengths of the rods may be obtained by easy linear constructions. The Author gives a sketch of the method of correcting Zeuner's diagram, introduced by MM. Coste and Manquet (*Méthode des Gabarits*).¹

The latter part of the Paper treats of valve-setting. The six following methods are analysed :

1. With equal lead.
2. Pambour's method.
3. With a minimum mean error.
4. With coincidence of the central position as obtained by the approximate and corrected diagrams.
5. With equal steam-admission in both strokes.
6. With equal work in both strokes.

Numerical examples of the several methods are worked out with the assistance of the diagrams previously developed. The Paper is copiously illustrated.

W. P.

Apparatus for controlling the Maximum Temperature in Steam-Boilers.

(Dingler's Polytechnisches Journal, Jan. 1882, p. 41.)

This device, constructed by Herr Richard Schwartzkopff, of Berlin, is intended to indicate by measurement of the temperature the sinking of the water-level below the minimum stand-point as well as the highest steam-pressure allowable.

The apparatus consists of two tubes inserted vertically in the boiler, one within the other. The external tube is of wrought iron and the interior one of brass. The outer tube reaches to the lowest water-level, and the inner tube somewhat lower.

¹ Tracés pratiques et exacts des épures de distribution de vapeur. Paris, Baudry, 1880.

The annular space separating the two tubes is closed at the upper end, a cap being screwed over the outer tube, while the inner tube has a turned flange fitting the cap and the top of the outer tube. The inner tube itself is closed at the lower end, and contains, at top and bottom, cups of porcelain, supporting rings of soft metal, that melt when heated to a certain temperature. Within the tube, and insulated by the porcelain cups, are two wires in communication with a battery, and when the metal rings melt, contact is made between the wires, and a signal bell is rung. The lower ring melts at a temperature corresponding with the highest permissible steam pressure. When the water-level sinks below the end of the outer tube the steam rises in the annular space, and the heat communicated by it to the inner tube melts the upper ring. A shield prevents steam bubbles from rising into the tube so long as it remains sealed by the water in the boiler.

G. E. S.

The Screw Steamer "Marie." By Prof. LEWICKI.

(Der Civilingenieur, 1881, p. 493.)

The steamer described in this Paper is a small screw boat, running on the Spree and Havel for towing and other purposes. The principal novelty is in the valve-gear of the engines. This gear (Klug's patent) is a modification of Hackworth's gear. It consists, for vertical engines, of an eccentric keyed on the shaft in the same angular position as the crank. The eccentric-rod is horizontal, and is supported about midway in its length by a swinging-link, the end of the eccentric-rod, away from the eccentric, being connected to a vertical connecting-rod which works the valve. The fixed point round which the suspending-link swings is so placed that the chord of the arc described by the end is inclined to the horizontal. In order to vary the expansion the fixed point is moved in an arc by a lever to which it is attached. This alters the inclination of the chord mentioned above, and consequently the motion of the valve also. To reverse the fixed point is moved over, so that the chord of the arc is inclined to the other hand in respect to the eccentric-rod. The improvement consists in suspending the eccentric-rod at a point between the valve-rod and eccentric; whereas in previous gears the valve-rod has been driven from a point between the suspended point and the eccentric.

This gear is found to give a distribution which is very suitable for vertical engines, as it keeps the lead constant for all grades of expansion both forwards and backwards, and gives more admission below than above the piston.

Extremely full particulars of the boat and engines are given, as also indicator-diagrams, the corrected diagrams for the moving masses, the diagram of the turning moments, &c., &c.

W. P.

*Indicator-Rig for Locomotives.*¹ By LEWIS F. LYNE.

(American Machinist, 1 April, 1882.)

For obviating the mechanical difficulties that attend the ordinary mode of applying an indicator to locomotives, the Author describes a simple construction of universal gear or "rig," designed and applied by himself, which he asserts is capable of being applied to all kinds of modern (American) outside-cylinder coupled engines, and to several styles of inside-cylinder. It consists of a light skeleton or framework of bars, bolted together and clamped to the cross-head guides, and carrying the centre of suspension for the upper end of a swinging lever, which receives an oscillating movement from the reciprocation of the cross-head slide-block; a wood sector attached to the lever rotates the indicator-drum by a cord in the usual way. Sketches with figured dimensions are given of the several parts composing the gear; and the proper mode of boring the pipe-holes for attaching the indicator to the cylinder or to the steam-chest is described in detail, as well as the construction of the three-way cock by which the indicator is placed in communication with each end of the cylinder in turn. The openings into the cylinder, which should be drilled ready beforehand in all engines prior to their leaving the shop, should be situated at right angles to the ports, instead of in line with them: so as to avoid the rush of steam past the openings, and the consequent production of wavy lines in the diagrams. The Author urges the frequent and general application of the indicator to locomotives, as a means of detecting faults in construction or working, of which he gives a glaring example.

A. B.

*The Water-Supply of the Toronto, Grey and Bruce Railway,
by Means of the Haggas Elevator System.*

By EDMUND WRAGGE, M. Inst. C.E.

(Journal of the Association of Engineering Societies, vol. i., p. 76.)

This railway, including a branch to Teeswater, is 191 miles in length, and runs for the greater part of its distance at a considerable altitude along the watershed of the northern streams feeding lakes Ontario, Erie, Huron, &c., the cold of this climate being very intense. Between the time of the construction of the line (1870-3) and 1878 pumping-houses, with tanks supplied by hand- or steam-pumps, were in use, the cost of their construction having been £3,014 (£14,666), or £15 16s. (877) per mile of railway, and the annual outlay in water-supply and repairs amounted to about £1,027 10s. (£5,000).

¹ Since this abstract was in print the original (illustrated) article has been reproduced in *extenso* in *Engineering*, May 5, 1882.

The new system adopted in 1878 consists in constructing underground tanks (in pairs close to and on each side of the track) at intervals along the railway. These tanks are lined with 3-inch planking, and fitted above with a boxing for the protection of a fixed 4-inch standpipe and bend, to which, when the engine-tender is being fed, is connected a short flexible hose attached to the Haggas elevator (a form of injector, explained by diagrams accompanying the original Paper), the latter being a fixture on the engine. The suction and delivery-pipes are 4 inches in diameter, and the steam-supply-pipe $1\frac{1}{2}$ inch in diameter. When the difference between the water and rail-levels does not exceed 8 feet the elevator will supply at the rate of 450 gallons per minute under a steam-pressure of 135 lbs. The cost of fitting up the twenty engines in use on the line with these elevators was at the rate of £10 5s. (£50) each, and the cost of the whole of the tanks, &c., £371 (£1,805·39) exclusive of royalty. The mean annual expenditure on repairs and maintenance during the time of service has been £48 15s. (£237·14).

The inconveniences arising from the old system were heavy original cost, trouble of preventing freezing, expense of pumping water, and cost of fuel for warming tank-house.

The disadvantages of the new system are: That water is not always to be obtained at a suitable level. The length of time occupied in taking water, which is probably twice as long as by overhead tanks. The inconvenience of feeding from the tank (of engine) to the boiler by an ordinary injector on account of the high temperature of the tank-water (this, however, should always be possible with injectors of newer type, which should feed with water of 120° , a temperature never attained in using the Haggas elevator). Lastly, the freezing of the standpipes during severe frost. This has been due to improper protection, and has only occurred on six occasions. The pipe is easily thawed by connecting it and the injector-waste together, and blowing steam down the hose.

Appendix A gives the saving effected in the cost of water-supply on the Prince Edward Island Railway by the use of this machine, the maintenance under this head having been reduced from £1,027 10s. (£5,000) to £20 10s. (£100). Appendix B refers to its adoption on 170 miles of the Canadian Pacific Railway, and the probable saving effected thereby.

D. G.

On a Rotary Pumping-Engine with Intermittent Action.

By R. SAUER.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxx., p. 15.)

The engine described by the Author has been erected at the Heinrich pit at the Mährisch Ostrau coal mines, belonging to the Northern Railway of Austria, in consequence of a sudden influx

of water, amounting to 1·2 cubic metre (264 gallons) per minute; the work required being the lifting of 2 cubic metres (440 gallons) of water from a depth of 200 metres (656 feet) at a speed of eight revolutions per minute. The system adopted is that of M. Kley of Bonn, which combines the Cornish principle of valves governed by a cataract, with the fly-wheel of the ordinary double-acting engine; the latter, however, taking no part in the movement of the valve-gear. The steam-cylinder is of 1·0-metre diameter and 1·9-metre stroke; the piston- and pump-rods being attached at equal distances from the centre of the main beam, which is prolonged within the engine-house so as to give a double length of arm to the fly-wheel connecting-rod. The object of the fly-wheel is twofold; first, to ensure complete safety by fixing the length of stroke in the main rod, and, secondly, to take up the momentum due to the acceleration of the piston while under full steam, giving it out again completely at the end of the stroke; for the latter purpose a comparatively small rotatory mass is required, the fly-wheel being brought to rest either before or behind the dead point of the crank, while the change of stroke is effected by the cataract. If the crank does not pass the dead-point the movement of the fly-wheel is reversed during the following stroke, producing an oscillating movement like the balance-wheel of a watch; and even when moving at greater speed when there is no actual pause; there is a perceptible retardation of the change of stroke, giving the necessary time for closing the pump valves.

If by the breakage of the main-rod of the pump spears, the equilibrium between the power and load is suddenly disturbed, the speed of the fly-wheel being very greatly increased, carries the crank quickly over the dead point, and drawing the cataract after it before it has had time to complete the stroke; the steam valve is shut and the engine necessarily stops.

The valve-gear is moved by a system of tappets from an auxiliary beam, worked from the main beam-centre. Although the engine is double-acting there is only one cataract, the steam admission valve on one side being closed simultaneously with the exhaust on the other. A portion of the work due to the expansion of the steam in the cylinder is therefore taken up in compression, but this is actually advantageous in retarding the speed towards the end of the stroke. The cold-water-admission to the condenser is regulated by the valve-gear, the injection being closed at the same moment as the steam-valve.

The main rod in the shaft is a rectangular cross in section, built up upon four angle-irons, varying in substance from 80 millimetres length of arm, and 12 millimetres thick, in the bottom part, to 100 millimetres and 12 millimetres in the middle, and 105 millimetres and 14 millimetres at the top. The total lift is 260 metres, of which 200 metres are divided over three plungers, and the bottom 60 metres over two drawing-lifts. The total weight of the rods in the shaft is 37·3 tons, the excess of which is counterpoised by balance-weights of 10·9 tons attached to the inner side

of the beam, between the points of attachment of the piston- and the connecting-rod.

The engine was built from M. Kley's designs at Prince Salm's engine works at Blansko; the total weight is 73½ tons.

H. B.

On Cold-Producing Machines and the Vapour of Ammonia.

By Prof. Dr. ZEÜNER.

(Der Civilingenieur, 1881, p. 449.)

In this Paper the Author examines the theory of those cold-producing machines in which the working substance is a fluid and its vapour, and in which a cycle is being continually performed that is the exact reverse of that of an ordinary steam-engine. The Author calls these machines cold-steam-engines (Kalt-Dampfmaschinen).

In such engines those fluids are used which boil at a low temperature under considerable pressure. In the "compression" machines the fluid is enclosed in a vaporiser, and as it boils it extracts heat from a surrounding tank containing the fluid to be cooled. As the vapour is formed it is pumped off from the vaporiser, compressed, cooled, condensed, and then allowed to flow as a fluid back into the vaporiser. In the "absorption" machine the vapour from the vaporiser is conducted into a vessel, where it is absorbed by another fluid, the fluid is then pumped into a boiler, where the absorbed vapour is driven off by heat and condensed in a condenser. In the absorption-machines, such as Carré's, ammonia-vapour is the only one which can be practically used. There is little difficulty in developing the theory of the absorption-machines, but universal results cannot at present be calculated, owing to the absence of the required experimental data.

The Author confines himself therefore to the compression-machines, and deals first with a theoretically perfect machine, consisting, as above, of a vaporiser, an exhausting and compression-pump, a surface-condenser, and a cylinder placed between the condenser and the vaporiser. In this cylinder a portion of the work is regained, which was absorbed by the pump. In the machines, as actually carried out, this cylinder is omitted, and the fluid is allowed to flow through a throttle-valve into the vaporiser.

The Author considers the thermodynamics of the compression machines in the same manner, and with the same notation, as in his "Grundzüge der mechanischen Wärmetheorie." He gives a numerical example of an ammonia-engine, working between the temperatures: -15°C. and $+20^{\circ}\text{C.}$ ($+5^{\circ}\text{F.}$ and $+68^{\circ}\text{F.}$), and the pressures 2.29 and 8.51 atmospheres. Supposing the vapour to be supersaturated at the commencement of compression, so that it

contains 90 per cent. of dry steam, the Author finds that at the end of the adiabatic compression the percentage has risen to 97·35, showing vaporisation; if the vapour had been dry saturated at the commencement of compression, superheating would have taken place. The latter case the Author considers separately.

For a machine, as above, to extract 36,000 calories per hour (142,848 British heat-units), working at 50 revolutions per minute, the double-acting pump would require a capacity of 0·0109 cubic metre (0·385 cubic foot), and the necessary driving-power would be 7·67 HP. This perfect machine would produce 47 kilograms (103·6 lbs.) of ice per HP per hour.

The Author next treats of the actual machines. For such a machine working between the above limits, the production of ice should be 43 kilograms (94·8 lbs.) per HP per hour; but this is never obtained in practice.

The nature of the vapour used has a great effect on the size of the machine; the relative capacity of cylinder required being:

Ammonia	1
Carbonic acid	0·16
Methyl chloride	1·8
" ether	1·8
Sulphurous acid	2·6
Ether	15·1

Bisulphide of carbon has also been proposed, but the Author considers this to be totally unsuited for the purpose, besides being worse than ether, as regards the cylinder-volume required.

The Author next treats of clearance and its effect on the indicator diagrams, and establishes formulas for the calculation of new machines.

The Author appends to the Paper some remarks on the vapour of ammonia, with the necessary calculations. Regnault¹ found the following empirical equation between the temperature t (degrees centigrade) and the pressure p (in millimetres mercury) for saturated vapour of ammonia:

$$\log. p = a + b a' + c.$$

Zeuner has recalculated the constants from Regnault's experiments, and finds:

$$\begin{aligned} a &= 5·5582655 \\ b &= -2·6366518 \\ c &= 31 \\ \log. a &= -0·0035023 \end{aligned}$$

In the absence of experimental data for the superheated vapour of ammonia, sulphurous acid, &c., Zeuner proposes an equation similar to that used by him for steam:

$$p v = BT - Cp^a,$$

¹ "Expériences," vol. ii., p. 596, et seq.
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p =pressure, v =specific volume, T =absolute temperature; B , C , n , are constants.

With this equation as a base, he has calculated for ammonia the very complete Table which is given in the Paper. This table he proposes to use until better experimental data are forthcoming.

W. P.

On a Diving-Bell Boat and a new System of Movable Weirs.

By M. DEBEIL.

(Annales des Travaux Publics de Belgique, vol. xxxviii., 1881, p. 521.)

In this Paper a description is given of a diving-bell boat used on the Seine for examining and repairing the weirs. It is intended to be used for maximum depths of 8 metres (26 feet 3 inches), and in currents up to 2 metres per second ($4\frac{1}{2}$ miles per hour). The apparatus consists of a steam-barge with a large well in the centre, through which the bell slides. The bell consists of a wrought-iron cylinder, about 7 feet in diameter and 13 feet high, so that for ordinary work on the Seine the top of the bell is above the surface of the water; for greater depths a temporary length of tube is attached to give access to the inside of the bell. The bell is divided into stages, with a working chamber below, and water ballast tanks and air locks above. The bell is raised and lowered by filling the ballast tanks with air or water. The boat is furnished with engines for compressing the air, raising the materials, and driving the warping winches.

The second part of the Paper is devoted to a new system of movable weir, introduced on the Seine by M. Caméré. The principal feature of this system consists in the method of closing the different bays by unwrapping a blind from a roll. The blind consists of strips of wood hinged together. It is fastened at the top, so that, as the roll is raised or lowered by a crab, the opening is enlarged or closed. After the blind is rolled up the dividing-girders of the several bays can be hinged round their top ends and lifted entirely out of the water, so as to leave a perfectly clear water way.

W. P.

Notes on Asbestos in Italy.

(Notizie statistiche sulla Industria Mineraria in Italia 1860 al 1880.)

The mining for asbestos in Italy is as yet limited to the Valtellina (Province of Sondrio), and to Piedmont (Province of Turin). The workings in the Province of Sondrio are situated in Val Malenco, in the Communes of Lanzada, Chiesa, Torre Santa Maria and Caspoggio.

The asbestos occurs in regular strata, varying in thickness from 3 to 4 inches, though in some cases it has been found 20 inches thick. The enclosing rocks are chloritic and talcose schists of a greenish colour, in which it is found, chiefly in fibrous masses of a yellowish-white colour, more or less cemented together. In some cases the fibres are long, firm, and resembling a skein of thread of a yard or more in length. Professor Taramelli has observed that asbestos abounds in the fissures of serpentine rocks. It often is accompanied by other minerals, amongst which Professor Cossa has found garnets of a green colour, in minute crystals, to which the miners give the name of "*Semenze dell' amianto*" (seeds of asbestos).

The excavations are carried on in about forty places, and generally speaking the enclosing rock is quarried by blasting. In some cases where too much sterile material would have to be removed, the workings are driven forward in the asbestos-yielding stratum, leaving pillars here and there to support the superincumbent rocks.

In Piedmont asbestos is obtained in the serpentine mountains of the Val d'Aosta, valley of Lanzo, Susa and D'Ossola, and chiefly in the communes of Emarese, Brusson, Challant, St. Anselme, Chatillon, Verrès, St. Vincent, Champorcher, Issogne Pontey, Chambave, Torgnon, Montjovet, Valfrato, Campiglia Soana, Ronco Canavese, Sugria, Usseglio, Chianoe, Coazzo, Craveggia, Autronapiana and Montescheno. It occurs in veins of $\frac{1}{2}$ inch to 4 inches in thickness; the length of these veins reaches in some cases 20 yards, but their depth is very limited. The best quality is found at Emarese; that of Campiglia Soana has the longest and finest fibres, but unfortunately often is decomposed; whilst that of Usseglio resists fire best. The asbestos of Valtellina, however, has the strongest fibres.

In 1878 the workings in the Valtellina produced about 80 tons of asbestos, and gave employment to two hundred persons, during seven or eight months, whilst those in Piedmont furnished 100 tons and employed two hundred hands. This industry, which is increasing, is in the hands of six firms, amongst them two English companies, one of which has established a manufactory at Tivoli, near Rome, whilst the others work up the raw material at Turin. The products manufactured are principally cardboard for steam-joints, packing for steam-engines, felt for covering pipes, boilers, &c., fireproof paper, mastic thread and incombustible cloth.

The raw asbestos at Lanzada is valued at 70 cents. per kilogram (about 3d. per lb.), whilst the cardboard and cord for packing, is sold at Turin at from 2.50 to 3.50 per kilogram (from 11d. to 16d. per lb.). At Rome the various products are sold at from 3.50 to 12 lire per kilogram (16d. to 4s. 6d. per lb.).

It is estimated that this industry gives employment now to about five hundred persons, of whom four hundred at the mines, and one hundred in the factories. The total production, which in 1872 was only 50 tons, in 1878 amounted to nearly 200 tons, of a value

of 200,000 lire (£8,000), and, taking into account the value of this substance in a manufactured state, the asbestos industry realises without doubt a million of lire (£40,000) annually. It is exported chiefly to Great Britain, Germany and the United States.

P. L. N. F.

Notes on the Production of Pozzolana in the Provinces of Rome and Naples.

By L. DEMARCHI and O. FODERÀ, Engineers in the Royal Corps of Mines.

(Notizie statistiche sulla Industria Mineraria in Italia del 1860 al 1880.)

Pozzolana is found abundantly in the neighbourhood of Naples, the pits of Bacoli near Pozzuoli being of excellent quality, the pozzolana of Montenuovo is particularly adapted for marine works, whilst that of Bassano, near Torre del Greco, is in considerable demand. At Naples, the best qualities are called *pozzolane di fuoco*, to distinguish them from the *pozzolane dolci*, which contain a large proportion of other earthy matter, and being found at a slight depth below the surface, and even in the city, these inferior qualities are largely used for ordinary buildings. The best qualities are of a dark brown colour, the yellow comes next, whilst that of a yellowish white is the least valuable. For lining water-tanks, a volcanic earth of a dark brown colour called *ferrugine* is much used. In the Neapolitan provinces *lapillo*, a product of volcanic origin, is much used, this material which is composed of fragments of pumice-stone and scoria, is of two qualities, the black and the white, and, mixed with ordinary lime, makes a very strong mortar, which is used for pavements and for covering buildings.

The pozzolana deposits, worked at Bacoli, Montenuovo and Vesuvius are, from their position as regards facility for shipping and vicinity to the railway, from the quality of the material excavated and quantity exported, the most important, and are all three open workings. The pits of Bacoli, though capable of furnishing 50,000 tons of pozzolana annually, do not, on account of the limited demand, produce more than 10,000 tons, which is delivered free of cost at 10*d.* per ton, the vessels taking it frequently as ballast, which can be disposed of at remunerative rates at other ports. The workings of Montenuovo, near Baja, produced 3,600 tons in 1880, of which $\frac{2}{3}$ screened, and $\frac{1}{3}$ rough, which was sold at 1*s.* per ton screened, and 10*d.* per ton unscreened. The pits of Bassano, near Torre del Greco, supply the Southern Railway Company. The screened pozzolana being delivered into trucks on a siding from the railway, at the rate of 1*s.* 11*d.* per ton. A screen with $\frac{3}{16}$ -inch meshes, being stipulated for in the specification.

Pozzolana occurs frequently in the volcanic zone of the province of Rome, and more especially in the neighbourhood of the capital, also in the Alban hills and Mountains of Viterbò. It is

The following is an analysis of pozzolana from the neighbourhood of San Paolo:—

Silica	47.66
Alumina	14.33
Magnesia	3.86
Sesquioxide of iron	10.82
Lime	7.66
Water	7.03
Alkaline and volatile elements	4.18
Sand	5.00
	<hr/> 100.00

The proportions (in volume) in use at Rome are :—

	Lime.	Possolana.
Rough rubble masonry (of tufa stone)	15	85
" (of pieces brick and tile)	25	75
Brickwork	80	70
Brick on edge	45	55
Tile pavement	36	64
Pavement of pebbles	22	78
Plastering	40	60

For brickwork, the proportion between the volume of bricks and that of mortar is 3 to 2.

The specific gravity of the pozzolana of Rome, according to Cavalieri, is 1·232; that of mortar 1·324. The resistance of this mortar to crushing was found by Rondelet to be 34·4 kilograms per square centimetre (488·13 lbs. per square inch) for mortar eighteen months old; 44·9 kilograms per square centimetre (637·13 lbs. per square inch) for mortar of the same age well rammed; and 51·20 kilograms per square centimetre (726·53 lbs. per square inch) for that of sixteen years and upwards. It may be observed that this mortar, which was tested at Paris, consisted of three parts in volume of Roman pozzolana, and two parts of slaked lime of Marly. The production of pozzolana in the neighbourhood of Rome, during the last ten years, has varied from 150,000 to 200,000 cubic yards annually, which, valued at 10d. at the pit, and at from 3s. 6d. to 4s. 2d. for carriage, would represent a value of £36,000 in the city. The exports vary from 10,000 to 20,000 cubic yards annually. The pozzolana sold in Rome is usually unscreened, whilst that exported is riddled in a kind of trommel of conical form, made of perforated sheet iron which is made to revolve upon its axis. In this operation about 40 per cent. of waste occurs, which is utilised at the workings for filling in.

P. L. N. F.

On Strontianite-Mining in Westphalia. By E. VENATOR.

(Berg- und hüttenmännische Zeitung, vol. xli., p. 1.)

The occurrence of strontianite, the native carbonate of strontia, in Westphalia, has been long known, and the mineral was to a small extent obtained by surface digging; but in the year 1871 it came suddenly into demand, being adapted for the recovery of crystallisable sugar from molasses in the Dessau Company's refinery, in whose interest the Author was intrusted with the examination of the district in the year 1874. Since that date it has become the seat of a large mining industry, employing twelve hundred men.

The district within which the mineral occurs extends northward from Hamm about 14 miles, and about 18 miles in greatest extent east and west; the largest development of workings being in the vicinity of the station of Drennsteinfurt, on the line from Hamm to Münster. The ground is nearly level, and except where covered with drift sand and northern erratics, consists entirely of bluish grey marls of the Upper Senonian (lower chalk) period; which is traversed by a series of lodes which individually vary very much in direction, but as a whole form two principal series, the first course of about S.W.—N.E., with a tolerably regular dip of 65° to 70° to S.E., and the second N.W.—S.E., and dipping S.W. at a somewhat higher angle. The former includes the more important

mines known as Dr. Reichardt's, belonging to the Dessau Company, which are upon a parallel series of veins extending for about 10 kilometres, without, however, being workable through the entire length. The longest continuous series of N.W.—S.E. veins is about $4\frac{1}{2}$ kilometres. Besides these, there are a great number of smaller veins in the district whose relations are not well defined, owing to the number of small woods and plantations intervening, within which mining operations are not permitted. The thickness of the veins varies very considerably, from $1\frac{1}{2}$ metre to 2 metres (5 to $6\frac{1}{2}$ feet) is not uncommon, and in one case 3 metres (10 feet) has been observed; but as a rule this dimension varies very considerably within short distances both in length and depth. The vein matter consists of strontianite, calcspar, and two varieties of marl, with occasional crystals of iron lignites. In one case fluid bitumen was found at a depth of 44 metres. The strontianite, which is very pure, containing about 96 per cent. of carbonate of strontia under the most favourable conditions, forms masses of 1 to $1\frac{1}{2}$ metre thick, and 16 to 20 metres (say 50 to 70 feet) or more in length. These finds have, however, diminished in depth, and at the lowest levels, 55 metres (180 feet) below the surface, the yield has sensibly diminished; the pure mineral being succeeded by an intimate mixture of strontianite and calcspar. The yield of the lode above was about 12 cwt. of clean ore per square metre, which has diminished to 3 and 2 cwt. in the bottom. The great amount of water met with in sinking is also very disadvantageous; and these circumstances, together with the high royalty, from 1s. 6d. to 2s. per cwt., or about 20 per cent. of the selling price, demanded by the freeholders, leads the Author to believe that the mining operations in the district are not likely to be of long continuance. The present production is estimated at about 3,000 tons of rough ore annually, about two-thirds of which quantity is raised in Dr. Reichardt's mines, and of this about 50 per cent. is subjected to mechanical preparation to fit it for market.

H. B.

Application of Electricity to the Prevention of Firedamp Explosions in Collieries. By L. SOMZÉE.

The best indicator of firedamp at present is the safety lamp; but, unfortunately, when the state of the flame indicates the presence of this gas, its proportion in the air is already nearly at explosive point, if, indeed, it be not so already, owing to the presence of coal-dust. As a rule, the miner's attention is only directed to the flame of his lamp when it is on the point of being extinguished; that is to say, when the danger is imminent. What is wanted, for the safety of the mine, is that the composition of the air may be instantly altered while there is yet time; and the first condition of warning instruments should be

the power to indicate the slightest trace of firedamp, as well as great sensitiveness to the presence of this gas.

Inasmuch as the safety lamp is now of general use in collieries, it has been utilised by the Author for giving the necessary warnings and indications. The case of the portable miners' lamp contains a small electric bell, whereas stationary lamps signal the danger in a special office, whence a check is kept upon the ventilators by bells placed in electrical communication. These warning lamps reveal the presence of firedamp before the flame of the safety lamps, generally employed for the purpose, gives any indication of its invasion. The elongation of the flame is, however, utilised in causing a dilatation apparatus to expand, and so make electric contact. Thin bands of two metals of unequal contractibility are employed—by preference steel and zinc soldered together with tin. In the large, stationary form of lamp this band is straight, and an increase of temperature causes it to bend in the direction of the less conductible metal. But in the miners' portable lamps the band is made to assume a spiral form, so as to increase the effect. The band is enclosed in an insulated chamber, formed by the annular space between a metallic gauze cylinder, surrounding the metal chimney of the Mueseler lamp, and the ordinary gauze covering. The inner metallic gauze may be replaced by a glass cylinder, as glass possesses the curious property of allowing heat accompanied by light to pass, but not heat alone. A screw increases or diminishes the extent to which the band must expand in order to make contact, according to a predetermined proportion of firedamp in the air at which it may be desired that the alarm be given. As long as the air in the mine remains in its normal condition, the apparatus is unaffected; but the least excess of gas increases the temperature in the insulation chamber, and causes the metallic band to expand. Experiments have shown that this appliance is so sensitive as to be affected by the breath, and also that the separate insulation chamber may be dispensed with. The modifications introduced into the lamp in no way detract from its element of safety.

Audible signals are given by transforming the safety lamp into a "singing" lamp by the addition of a sonorous tube placed over the flame, and within the slightly elongated metal chimney. The tube is again surmounted by the receiving instrument of a telephone placed in electrical communication with a central office. A horizontal wire gauze is placed over the flame, which, however, does not penetrate it in a normal condition of the atmosphere. But, when the flame becomes elongated owing to the presence of gas, it heats the gauze to redness, passes through it, and acts upon the sonorous tube, the sounds being transmitted by the vibrating membrane of the telephone. In a large size of lamp, two or more tubes are used, of various lengths and diameters, producing different notes, each being arranged so as to sound when the proportion of gas reaches a determined percentage.

The electrical indicator of minute quantities of firedamp or

carbonic acid depends on the fact that, while air and simple gases practically undergo no change of temperature under the action of radiant heat, compound gases and air mixed with a gas absorb non-luminous calorific rays. The flame of a safety lamp is deflected against a copper plate, which projects rays of heat into two hollow, air-tight and horizontal cylinders of glass or brass, closed by plates of rock-salt, slight thicknesses of which are diathermous. One is filled with pure air, and the other with air drawn by a tube from any part of the mine to be tested. The ends of the cylinders farthest from the source of heat terminate in conical reflectors, which concentrate the radiant heat emerging from the tubes, and direct it against the poles of a thermo-electric battery in communication with a galvanometer. As long as the composition of air in the two tubes remains the same, that is to say, so long as the air of the mine is not vitiated by deleterious gases, perfectly equal quantities of heat will be communicated to the two poles, and the index of the galvanometer will mark zero. But with the slightest trace of gas mingled with the atmosphere one of the tubes will contain a mixture, the molecules of which possess in a high degree the power of intercepting heat-waves, the equilibrium will be destroyed, and the heat reflected by the tube supplied with pure air will exceed that of the other and cause the deflection of the needle. A single apparatus may be supplied by several tubes leading from different points in the workings, and, if the flame be an objection, the source of heat may be a Leslie cube filled with boiling water, and coated with lamp-black to increase its power of radiation.

An alarm, permitting of detecting slight quantities of firedamp or carbonic acid, depends upon the mechanical power of an osmotic current to close an electric circuit in connection with bells. In view of the future lighting of collieries by electricity, electro-chemical appliances, based upon the reactions produced between different bodies under the influence of the electric light, and giving calls at all the stations of observation, are proposed as warning instruments, and also as means for preventing the mixture of air and gas from attaining the proportion when it becomes explosive.

Instruments on one or other of the above systems should be placed at carefully chosen and well-determined points, distinguished by letters or numbers, in the underground workings. They would be connected by wires with bells and indicating instruments, bearing corresponding letters or numbers, surmounting a plan of the workings, in which the various stations of observation were clearly defined in a special office on the surface. On hearing an alarm, the engineer would, by a glance at the plan, see the nature of the danger, its imminence, and the direction from which it proceeds. He would then signal or telegraph the necessary orders to the engine-man in charge of the ventilator and to the ventilation gang underground, so that the air-current might be slackened or intensified, and also directed as occasion required, thus preventing the atmosphere at any particular spot from

becoming explosive. At the same time, the bells in the portable safety lamps would warn the miners to retire to a place of safety and to extinguish their lamps, if, indeed, the latter were not made self-extinguishing, on the firedamp attaining a given proportion in the atmosphere.

J. W. P.

On Pit-Ropes. By Herr WENDEROTH.

(Zeitschrift für das Berg-, Hutten- und Salinen-Wesen, vol. xxx., p. 77.)

In the year 1872, in the interest of public safety, a statistical inquiry into the life of pit-ropes was commenced by the Oberbergamt of Dortmund, and subsequently in 1877 similar inquiries were commenced by the Board of Management of the Royal Collieries at Saarbrücken. The Author gives the results of these inquiries for the four years 1877-1880.

There were used during that period—

			Districts.	
			Dortmund.	Saarbrücken.
Flat ropes of cast-steel wire	.	.	87	27
" " soft iron "	.	.	18	20
" " aloe fibre .	.	.	19	6
Round " cast-steel wire .	.	.	388	42
" " soft iron " .	.	.	210	191
			722	286

In a Table, of which the following is an abstract, the first cost and work done in millions of kilogrammetres are given together, with the calculated cost per metre-ton (1,000 kilograms raised 1 metre) the latter in pfennige of $\frac{1}{100}$ marks—

Class of Rope.	Dortmund.			Saarbrücken.		
	Cost.	Duty.	Cost per Metre-ton.	Cost.	Duty.	Cost per Metre-ton.
	Marks.	Millions of Kgmetres.	Pf.	Marks.	Millions of Kgmetres.	Pf.
Cast steel, flat .	204,409	1,782,232	0·01149	24,965	120,443	0·02072
Iron " .	24,215	171,124	0·01415	16,324	132,483	0·01232
Aloe fibre " .	63,258	1,337,250	0·00556	7,491	39,428	0·01899
Cast steel, round	522,447	9,221,403	0·00567	54,587	686,735	0·00794
Iron " .	134,198	2,632,815	0·00509	129,826	2,647,937	0·00490

The greater apparent cost at Saarbrücken is due to the circumstance that in that district the miners travel entirely in the cages, so that the ropes are condemned when the slightest defect becomes apparent, or even in some cases when a particular fixed duty has been done, without reference to their condition.

The proportion of sudden breakages of ropes was—

	Dortmund.	Saarbrücken.
In 1877	8.98 per cent.	7.96 per cent.
" 1878	9.40 "	1.80 "
" 1879	5.23 "	6.89 "
" 1880	4.70 "	3.18 "

No fatal accidents due to travelling in the cage had occurred in the latter district.

From this Table it appears that the life in days is not much longer in the Dortmund than in the Saarbrück district, although the duty is nearly twice as great. This is due to the greater depth of the pits in the former district, necessitating a more rapid rate of winding and shorter stoppages than in the latter.

The comparative duty and life of a rope in the two districts was—

	Dortmund.		Saarbrücken.	
	Average Duty.	Life.	Average Duty.	Life.
	Millions of Kilo-grammetres.	Days.	Millions of Kilo-grammetres.	Days.
1877	23,787	554	10,888	444
1878	26,956	554	12,099	429
1879	28,971	539	14,363	538
1880	36,879	577	14,034	535

In regard to the materials, flat ropes of cast steel are the least economical, and, although somewhat lighter than those of iron wire, cannot be recommended. Flat aloe ropes at Dortmund are the cheapest of their class, and cost even less than round ones of cast steel. Notwithstanding this advantage their use is only exceptional, while in France and Belgium they are found in almost every mine.

At Kleinrosseln the largest private mine in Lorraine, aloe fibre ropes are used; nine were expended in the year 1880. The cost was 28,151 marks, the duty 282,876 million kilogrammetres, corresponding to 0.00,905 mark per metre-ton. The average life was 770 days.

These figures are not so favourable as those of the Dortmund district, but as all of the ropes were used in drawing men, they were not so completely worn as they might have been when laid aside. The cost was not, however, much higher than that of the round steel ropes at Saarbrücken. Taking into consideration the circumstances that the weight of the rope is almost completely counterpoised in the shaft, which allows lighter, and therefore cheaper winding engines to be used, and the increased safety, from the fact that sudden breakages are almost unknown when a moderate amount of care is taken in supervision, the Author considers that more attention should be paid to the use of aloe fibre than latterly has been the case in Germany.

Round ropes of cast steel have not turned out as they were expected to do. The error of using too hard a quality has been general, as in most of the condemned ropes, whether flat or round, the wires show no sign of wear or stretching, but have broken from repeated bending.

Latterly a medium soft quality of crucible steel, with an ultimate tensile strength of 114 to 120 kilograms per square millimetre, with an extensibility of 1 to 2 per cent., has been adopted at Saarbrücken. The stoutest wire, No. 11, must stand bending through a right angle, with a curvature of 5 millimetres radius, from four to six times, and the thinnest, No. 19, from fourteen to fifteen times.

Round ropes of good charcoal iron wire are still by far the cheapest in use. The best tensile strength is 50 kilograms per square millimetre, or from 50 to 60 kilograms for the harder qualities when soft drawn (unannealed). By annealing the strength is diminished about $\frac{1}{3}$. The extensibility is in the first case 1 to 2 per cent., and in the latter 15 per cent. The number of rectangular headings is 4 to 5 for No. 11, and 12 to 13 for No. 19 wires.

For very deep mines cast steel ropes appear to be a necessity, as the experiments with those of phosphor-bronze, Bessemer, and open hearth ingot-iron have not turned out as favourably as was expected.

Careful handling in all cases exerts an important influence on the duration of ropes. Above all things it is necessary, especially with steel ropes, to protect them from rust, and the Author comments unfavourably upon the careless way in which new spare ropes are left exposed to the vicissitudes of the weather. In order to preserve these unimpaired they should be kept in a dry place, but not too warm, and especially clear of leaky steam-pipes.

Great stress is also laid upon the necessity of periodical lubrication, which should be done at intervals of eight to fourteen days, according to the amount of wet in the shaft. The lubricant must be greasy, but not acid, and must not be allowed to harden, as in that condition it allows rust to form between it and the wire, so that a rope that appears to be well greased may be corroded to a sensible depth.

H. B.

The Thomas and Gilchrist Dephosphoration Process.

By C. WALRAND.

(Revue universelle des Mines, Sept. and Oct. 1881, p. 380.)

The Author has gained much information and practical knowledge of the process, both at the Creusot Ironworks, and at Hutta Bankowa, his notes being founded upon a careful observation of over 2,000 conversions (blows).

The dolomite or limestone best suited for the manufacture of the basic lining should contain the constituents mentioned below in the following proportions :—

	Per cent.
Silica	4 to 0
Alumina and oxide of iron	4 " 8
Lime	52 " 28
Magnesia	0 " 18
Volatile matter	40 " 46
	<hr/>
	100 100
	<hr/>

This basic material can either be used in the form of burnt bricks, or as a paste rammed into place by the workmen. This second method would appear to be the more economical.¹

In making the paste, the dolomite is first burnt, then crushed to powder and mixed with some binding material, such as anhydrous tar.

When the calcination is conducted in a Siemens' furnace, the clay thus made only costs 45 francs (36s.) per ton, and this price can be lowered by using either Hoffmann's kiln, a cupola furnace, or a regenerative gas-reheating furnace.

At Angleur near Liège a cupola furnace of 1·30 metre (3 feet 4½ inches) in diameter is used which produces 12,000 kilograms (26,455 lbs.) of calcined material per day of twenty-four working hours, burning 2,500 kilograms (5,511½ lbs.) of coke for lighting up, and 750 kilograms (1,655 lbs.) of coke per ton of dolomite. In using this material it appears preferable to mould the paste into bricks, by means of a powerful press, and to line the converter with these unburnt bricks, which are claimed to be more compact than a simple lining of rammed clay.

The best bottoms are made out of siliceous twyers and basic rammed clay, which will last out 18—20 "blows." The life of the perforated bottom would probably be increased by forming it of pressed bricks, into which the siliceous tubes could be introduced.

The cast iron to be treated in the basic converter should be of about the following composition :—

	Per cent.
Silica	0·05 to 0·10
Manganese	1·50
Sulphur	0·06 " 0·15
Phosphorus	2·50 " 1·20

Silica is injurious to the process, since its presence entails a longer interval before the melted slag can become basic, and makes it necessary to prolong the afterblow. It cannot, however, be entirely dispensed with, as, if it were, the action would not be sufficiently rapid; nevertheless, in the basic converter the silica

¹ In order to make it into bricks a somewhat expensive plant is necessary. The cost price of these bricks in France amounts to 65 francs (52s.) per ton.

has a diminished calorific effect, and is less energetic than in the silicic converter, as the heat which it produces is in a great measure absorbed by the formation of the slag.

Manganese is favourable to the elimination of sulphur. With 1—1·5 per cent. of manganese a total amount of 0·15 per cent. of sulphur can be successfully dealt with, which would be impossible in dealing with cast iron containing no manganese whatever. Moreover, if manganese were absent the “afterblow” would produce an oxidized metal, which would render it impossible to determine the quantity of spiegel which should be added in order to secure a given hardness, whereas with a little manganese it is possible to obtain an arbitrary percentage of carbon.

The quantity of sulphur in cast iron may exceed the given limits if it be treated in a second fusion. In melting in the cupola furnace a mixture of cast iron, containing sulphur, spiegel, and a given proportion of lime, nearly all the sulphur is eliminated. Thus, cast iron containing 0·7—1 per cent. of sulphur, will only contain 0·08—0·12 per cent. on being withdrawn from the cupola, and will give a dephosphorised steel yielding only 0·03—0·04 per cent. of sulphur.

As to the quality of the dephosphorised metal, M. Walrand is of opinion that every kind of steel can be produced. It is quite possible to obtain a hard regular steel, provided that the pig contains at the commencement from 1—1·5 per cent. of manganese.

For soft products the basic process is preferable to the siliceous, since they can be obtained more easily by this method. It is simply necessary to start with a pig iron containing from 1·5—2 per cent. of manganese, and to avoid recarbonising the metal. A very slight addition of rich ferro-manganese is advisable without being indispensable.

It would appear to be established that dephosphorised steel is more subject to flaws than hematite steel; this is unimportant in soft steels, which always show some flaws, invariably internal. In hard steels the flaws are found close to the surface of the ingot and have a tendency to strip or peel off, especially in cases where a little sulphur is present, when the steel ingots present a most unfavourable appearance. In making hard dephosphorised steel it will be well not to exceed 0·06 per cent. of sulphur; with less than 0·04 per cent. the rolling will be good, as the flaws are first elongated and finally disappear. This defect can also be remedied by increasing the section of the ingot either by hammering or by diminishing the pressure in the first grooves in the rolling mills.

The Author then points out the special modifications required in carrying out the basic process. He is of opinion that the actual life of the linings and bottoms is sufficiently prolonged to allow of work being continually carried on with two converters only.

The article concludes by an analysis of cost from a French point of view. According to the Author, cast steel made by the Gil-

christ process fetches 56·40 francs (44s.) in the Meuse and Moselle districts, whereas the average cost price of Bessemer steel in France is 100 francs (£4). The cost price of steel made by the Gilchrist process is based on the following figures:—

	Kilos.	Lbs.	Per ton of 1,000 kilos.	F. C.
Oolitic ores . . .	2,800	(6,172)	at 3 f.	= 8·40
Sigen ores . . .	150	(330)	„ 40 f.	= 6·00
Coke . . .	1,200	(2,644)	„ 25 f.	= 30·00
Cost of production . . .	..	..	..	12·00
				<u>56·40 say £2 5s.</u>

This price leaves a liberal margin, since manganiferous ores can certainly be obtained much cheaper at Giessen.

For steel made by the basic process the accepted loss is 14 per cent. and 10 per cent. for the acid process, which leads to the following cost price, based on a first fusion.

	Bessemer Steel.		
	Cost per 1,000 Kilograms.	Quantity consumed.	Value.
	F. C.	Kilograms. Lbs.	F. C.
Cast iron . . .	100·00	1,031 = 2,470	108·00
Spiegel . . .	140·00	69 = 152	9·66
Coal . . .	10·00	190 = 418	1·90
Coke . . .	25·00	50 = 111	1·25
Fire-clay, &c. . .	..	54 = 119	1·15
Limestone . . .	..	..	..
Ingots . . .	110·00	15 = 33	1·80
Labour . . .	..	..	4·00
General expenses . . .	..	..	4·00
			<u>126·76 say £5 1s. 6d.</u>
	Dephosphorated Steel.		
	Cost per 1,000 Kilograms.	Quantity consumed.	Value.
	F. C.	Kilograms. Lbs.	F. C.
Cast iron . . .	56·40 = 2 5	1,050 = 2,314	59·23
Spiegel . . .	140·00 = 5 12	90 = 190	12·60
Coal . . .	..	220 = 484	2·20
Coke . . .	..	70 = 154	1·75
Fire-clay, &c. . .	..	75 = 165	4·66
Limestone . . .	10·00 = 8 0	165 = 352	1·65
Ingots . . .	..	15 = 33	1·80
Labour . . .	..	..	5·50
General expenses . . .	..	..	5·00
			<u>94·49 say £3 4s. 6d.</u>

It is believed that the foregoing conditions represent pretty nearly the situation of the new "Aciéries de l'Est," as compared with the older steel works of Central France, but do not apply to

other districts such as the Nord, the Gard, the Gulf of Gascony, &c. If the cost be considered item by item so as to compare it with the existing conditions of the Belgian Iron Industry, that is to say, if the Gilchrist steel be assumed to cost 70 francs (56s.), Bessemer 90 francs (72s.), spiegel 120 francs (96s.), coke 20 francs (16s.), the conclusion arrived at is that a Bessemer steel ingot can be produced in Belgium for 114·90 francs (92s.), and the Gilchrist ingot for 106·60 francs (85s.), without taking patent right into account. In order to establish a rigorous comparison it would be necessary to take into account existing differences between France and Belgium as to labour, price of refractory products, &c.

The general conclusion arrived at by the Author is that assuming the steel ingot to cost 95 francs (76s.), rolled rails may be produced for 120 francs (96s.), and that under such conditions it will be possible for France to compete with England, Belgium, and Germany. G. S.

The Influence of Manganese on the Strength of Iron.

By Dr. H. WEDDING, Prof. FINKENER, and Prof. SPANGENBERG.

(Verhandlungen des Vereins zur Beförderung des Gewerbflusses, 1881, pp. 509–526.)

A prize of £100 having been offered by the Society for the Encouragement of Industry in Prussia for the best series of alloys of iron and manganese, two manufacturers submitted samples, the examination of which is detailed in this Paper. According to the conditions of the competition twenty rods of iron were to be sent in, ten of an alloy of iron and manganese with less than 0·6 per cent. carbon, and not more than 0·4 per cent. impurities; and ten of an alloy rich in carbon, and in which the impurities were not to exceed 0·6 per cent. The proportion of manganese in the first series of samples was to increase gradually from 0·5 to 5 per cent., while the amount of carbon in the second series was to vary by increments of at least 0·15 per cent. The rods or bars were to be perfectly homogeneous, and 50 centimetres (19·685 inches) long by 40 millimetres (1·575 inch) thick.

The chemical examination, which included a careful analysis of each bar, was carried out by Professor R. Finkener, while the mechanical tests were entrusted to Professor Spangenberg. The analyses of the first ten bars showed that the proportion of manganese varied from 0·42 to 0·88 per cent., while that of the carbon was from 0·36 to 1·94 per cent. The second series of ten alloys by the same maker were found to contain carbon in proportions varying from 0·29 to 0·74 per cent., instead of the stipulated minimum of 0·6 per cent. The percentage of manganese rose from 0·24 to 4·37. The first series of samples submitted by another firm contained: manganese, 0·32 to 11·4 per cent.; carbon, 0·58 to 2·42 per cent.; maximum impurities, 0·92 per cent. The second series

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showed a gradual increase of manganese from 0·35 to 2·21 per cent., the amount of carbon rising at the same time from 0·58 to 2·9 per cent. From these analyses, which are given in detail, it appeared that none of the competing series completely fulfilled the prescribed conditions with regard to chemical composition. It was found in carrying out the physical experiments with these alloys that they were extremely hard, and so brittle that they frequently flew into numerous pieces when subjected to a transverse strain. The tensile strength did not appear to bear any fixed relation to the amount of carbon or manganese present, and in many cases the alloy was not homogeneous. The impurities, especially the phosphorus, contained in the samples tested may have had more influence on the mechanical results than either carbon or manganese.

W. F. R.

Tests of Iron and Steel. By the BUREAU VERITAS, Brussels.

(The original MS. tables from which this Abstract is made can be consulted at the Institution.)

The Bureau Veritas was founded at Antwerp in 1828, for affording technical information to underwriters and Marine Insurance Companies as to the rating of vessels, in the same way as "Lloyd's," established in 1834. When Belgium became separated from Holland in 1830, the seat of the society was transferred to Paris, and during the siege of that capital in 1870 to Brussels. Meanwhile its rating acquired such authority that vessels were built under its survey; and its register now includes more than ten thousand vessels.

When mild steel was proposed as a material for shipbuilding, the Bureau Veritas commenced a series of comparative experiments between steel and iron of various makes and from different countries, with a view to determine what reduction could be made upon scantlings where steel was substituted for iron. These experiments are still being continued; and, early in 1880, the society erected a Thomasset testing machine at their head office in Brussels, so that the tests might be carried out exclusively by their own officers.

The following Table gives the mean results of the most important and instructive experiments, selected from a large number made last year (1881). The irons were tested chiefly by way of affording a comparison with the new metal, and to demonstrate how far the latter is to be preferred for shipbuilding.

The initial tension to which the test-pieces were subjected was 10 kilograms per square millimetre (6·35 tons per square inch), with the exception of those from the Moss End Iron and Steel Works, Glasgow. In all cases, the tension was gradually increased

BUREAU VERITAS.

MEAN RESULTS OF TESTS OF IRON AND BESSEMER STEEL IN 1881.

N.B.—The length of each test-piece was 200 millimetres = 7·87 inches.

Number of Sheets.	Description.	L, Longitudinal, T, Transverse.	Origin of Samples.	Elongation per Cent. on 500 mm	Breaking Strain per Square Inch.	Limit of absolute Elasticity		Observations.
						Per Square Inch.	Elasticity in Millimetres on 500 mm.	
1	Steel .	T	Degerfors, Sweden .	18·7	Tons, 30·2	Tons, ¹ 19·2	0·37	Silky fracture.
2	" .	L	" .	19·7	30·4	19·9	0·35	" "
3	" .	T	Seraing, Belgium .	22·4	29·5	17·7	0·40	" "
4	" .	L	" .	21·2	29·0	17·8	0·46	" "
4	" .	Angle	" .	21·9	29·6	18·6	0·48	" "
5	No. 2 iron	L	" .	7·0	21·25	12·35	0·32	Sooty appearance.
5	"	T	" .	3·3	17·45	11·05	0·30	" "
5	No. 3 iron	L	" .	8·6	20·95	12·4	0·32	" "
5	"	T	" .	5·55	20·65	14·6	0·30	" "
6	"	Angle	" .	10·0	22·6	13·6	0·28	" "
7	"	L	" .	4·5	24·1	18·4	0·35	" "
7	"	T	" .	2·5	20·3	17·1	0·30	" "
8	Steel .	L & T	Steel Co. of Scotland .	19·0	28·3	15·7	0·23	Silky fracture.
9	" .	"	Acieries de Creil .	16·0	32·7	20·0	0·32	" "
10	" .	"	Moss End, Glasgow .	25·8	23·4	14·0	0·27	" "

¹ Above this strain the samples took a permanent set.

by 1 kilogram per square millimetre (0·635 ton per square inch), referred to below as increment of tension, until fracture ensued.

The elasticity of the test-pieces given in the Table in millimetres, on a length of 200 millimetres (7·87 inches), is the elongation caused by the recorded strain just short of the permanent elongation; and the greatest strain registered before a permanent set takes place, with the elongation caused by that strain, is entered in the columns headed "Limit of absolute elasticity."

The elongation corresponding to each strain was recorded as soon as no further elongation took place at that strain; and, after the elongation had been registered, the pressure was taken off, and a note made of the proportion of that increment of elongation which remained permanent.

It is frequently supposed that, if a test-piece be subjected to repeated pulls, each of which separately may be insufficient to cause a permanent set, the tension corresponding to the limit of elasticity is gradually increased; and an explanation has been offered by the supposition that the repeated pulls have the same effect as hammering the sample. To remove the strain, therefore, after each elongation caused by that strain, has the disadvantage, under this hypothesis, of causing the limit of elasticity to advance before the experimenter, and therefore of tinging the results with error.

For this reason, the samples obtained from steel plates manufactured by Messrs. Neilson & Co. were treated in a slightly different manner from the remainder. The initial tension to which they were subjected was 5 kilograms per square millimetre (3·175 tons per square inch); the successive increments of tension, however, remaining the same, viz., 1 kilogram per square millimetre. In this case the tension was not taken off after each increment, although the elongation caused by that increment was duly registered. The limit of elasticity of the samples was determined by the point at which the elongation began to increase in a marked manner; and numerous experiments have borne out the correctness of this view.

An instance is afforded by one of the samples, marked No. 528. Up to 23 kilograms per square millimetre (14·6 tons per square inch) the elongation increases gradually from zero to 0·35 millimetre by successive increments of 0·025 millimetre; but, at this point, 1 additional kilogram per square millimetre (0·635 ton per square inch) caused the piece to elongate from 0·35 to 0·425 millimetre; that is to say, an increase of 0·075 millimetre, after which the elongation increased rapidly. The limit of absolute elasticity is, therefore, put at 23 kilograms per square millimetre (14·6 tons per square inch), showing an elastic elongation of 0·35 millimetre on a length of 200 millimetres (8 inches), or 0·175 per cent.

In test No. 424, at a tension of 41 kilograms per square millimetre (26 tons per square inch), the bar showed an elongation of 16·75 millimetres, and was then left for sixteen hours. The next

day, another increment of tensile strain was added; but, as the molecules of the test-piece had had time to arrange themselves under the pull to which they were subjected, no further elongation took place with 42 kilograms per square millimetre (26·67 tons per square inch). Nor was any further elongation noticed until the tension was increased to 43 kilograms per square millimetre (27·3 tons per square inch); and then one additional increment of tension caused fracture, the breaking strain being 44 kilograms per square millimetre (27·9 tons per square inch).

Sample No. 425 showed, at a tension of 31 kilograms per square millimetre (19·6 tons per square inch), an elongation of 1·85 millimetre, when it was left for forty hours. On resuming the experiment, an additional kilogram per square millimetre (0·635 ton per square inch) was added; but no further elongation took place. Another increment of tension was then added, making a total strain of 33 kilograms per square millimetre (20·9 tons per square inch), when the piece became elongated by 3·75 millimetres.

More complete and perhaps conclusive evidence was afforded by Test No. 528, on a sample of steel from the Moss End Iron and Steel Works, Glasgow. Under a tensile strain of 35 kilograms per square millimetre (22·2 tons per square inch) the bar showed an elongation of 4·5 millimetres, when it was left for sixteen hours. An additional increment of tension only caused a further elongation of 0·05 millimetre, making a total elongation of 4·55 millimetres for a tension of 36 kilograms per square millimetre (22·86 tons per square inch). Another increment was then added, making a total of 37 kilograms per square millimetre (23·5 tons per square inch), when the corresponding total elongation amounted to 5·65 millimetres. At a tension of 41 kilograms per square millimetre (26 tons per square inch), the piece showed an elongation of 8·85 millimetres, when it was again left for sixteen hours. On another increment of tension being added, making 42 kilograms per square millimetre (26·6 tons per square inch), the elongation only amounted to 9 millimetres; that is to say, an increase of only 0·15 millimetre, although the two previous increments of tension (without interval between them) had caused an increase of elongation amounting to 1 millimetre for each increment. The next increase of tension, making 43 kilograms per square millimetre, caused the piece to elongate 2·2 millimetres, thus making the total elongation for that strain 11·2 millimetres.

The inference drawn from these tests is that the elastic elongation is a most important factor in determining the structural value of a metal, the total elongation being much influenced by the great reduction of sectional area which takes place immediately before fracture. The information acquired by the experiments warrants the directors of the Bureau Veritas in allowing a reduction in scantlings of from 10 to 25 per cent. in the case of steel as compared with iron; but, at the same time, each individual case is decided upon its own merits, without a hard-and-fast line being laid down.

J. W. P.

The Alexandrowsky Steelworks. By O. T. TELLANDER.

(Jernkontorets Annaler, 1882, p. 3.)

These works, situated near St. Petersburg, are among the most important of their class in Russia. They were commenced at the end of 1877, and set to work in March 1879, since which time they have been in continuous operation. The products are steel rails for the Government lines, and projectiles and guns in cast steel, these latter being made according to the Terre-Noire process.

The plant comprises seven melting and six preparatory heating furnaces on the Siemens' Martin principle, which are arranged in a single line about 350 feet long; the heating and melting furnaces alternate with each other. Six of the melting furnaces are of 7 tons capacity, while the seventh takes a 9-ton charge. The latter is 1 metre larger than the smaller ones, and has two openings instead of only one on the working side. The gas producers are placed in a line parallel to the furnaces, there being four to a melting and three to a heating furnace, and each pair of furnaces has its own chimney. The capacity of the four regenerator chambers under each melting furnace is 43·6 cubic metres, and as the consumption of coal is about 9 tons daily per furnace, the capacity per ton of coal per day is 4·8 cubic metres.

The hearth bottom of the melting furnaces, which are carried upon 50-millimetre cast-iron plates, are made of a lower layer of Dinas bricks 65 millimetres, covered by 180 millimetres of a mass formed of 42·5 per cent. of clean sand from Lake Ladoga, 42·5 per cent. of burnt quartz, and 15 per cent. of Russian fireclay; the sides and roof are of Dinas bricks. The average working life of the furnace is two hundred and thirty-two charges, the highest attained being two hundred and eighty. The roof requires partial renewal after about one hundred and fifty charges. About ten days are required for the complete renewal of the hearth and walls of the furnace.

The ingot-moulds are carried on a turn-table, so that each one may be brought in succession under the tap-hole of the furnace, no ladle being used. They are lifted and removed by a transportable steam-crane running on a line of railway parallel to the longitudinal axis of the furnaces.

The materials chiefly used up to 1881 were—

1. English hematite pig, averaging 3 per cent. of carbon, 1·9 per cent. of silicon, 0·035 per cent. of sulphur, and 0·078 per cent. of phosphorus.

2. Good Bessemer scrap from England and France.

3. Broken rails and other scrap produced in the works.

4. Worn-out rails from the Russian railways, with about 0·3 per cent. of phosphorus.

5. Swedish Spiegel from Schisshyttar, with 8 to 15 per cent. of manganese.

6. *Ferro-manganese* from *Terre-Noire*, with 50 to 55 per cent. of *manganese*.

7. *Silico-ferro-manganese*, from *Terre-Noire*, with 4 to 10 per cent. of *silica*.

8. Rich pure iron ore from Sweden.

Good English coal is used in the producers.

Originally the charges were made up as follows :—

Pig iron	29
Steel scrap	37
Iron rails	49
Ferro-manganese	3
	—
	100
	—

The finished rails contained 0·15–0·20 per cent. of phosphorus, carbon 0·25 per cent., and manganese 0·45 per cent. As rails of this composition would not stand the extreme cold of the Russian winter, the proportion of iron rails and pig metal was reduced, that of steel scrap being correspondingly increased, having per charge—

Pig iron	15
Steel scrap	66
Iron rails	15
Spiegeleisen	1
Ferro-manganese	3
	—
	100
	—

giving a product with 0·08–0·10 per cent. of phosphorus, 0·3–0·4 per cent. of carbon, 0·8–0·9 per cent. of manganese, and only traces of silicon. At present the average amount of pig used is about 20 per cent. The details of eight successive charges both in the larger and smaller furnaces are set forth in a tabular form by the Author.

In the smaller furnace the average time of working a 7-ton charge is six and a quarter hours, of which one hour and twenty-five minutes are required for repairing the furnace, tapping, heating up and charging. The time required for filling the ingot moulds is from ten to twelve minutes. The yield from a 7-ton charge is from thirteen to fourteen ingots, each of the weight of two rails, or from 525 to 550 kilograms.

The ore reduction process was tried experimentally with charges containing 36 per cent. of pig metal, and 8 per cent. of a somewhat quartzose Swedish ore containing 55 per cent. of iron, which was added to the bath in quantities of about 120 kilograms at intervals of about ten minutes, being first brought to a dull red heat in the heating furnace. The total amount of ore added was about 500 kilograms. It was found, however, from its low specific gravity, that it was difficult to incorporate with the bath, and, floating on the surface, it was mostly taken up by the slag,

which consequently became very basic, and corroded the furnaces to such an extent that, after making fifteen charges, the use of ore had to be abandoned.

The ingots for rails are taken direct to a Bicheroux heating furnace with a bed 8.25 metres long, and 1.5 metre broad, which is capable of re-heating one hundred and forty ingots, weighing 75 tons, per day, with a consumption of coal varying from 11 to 13 per cent. of the weight of the work heated, according as the latter is charged warm or cold. The heated ingots are passed ten times through a double cogging mill, which reduces the thickness from 250 to 210 millimetres, and are then re-heated in a Siemens' furnace and rolled off to finished rails by thirteen passes through the rail mill. Both mills are worked by the same engine, which has three horizontal direct-acting cylinders and is of 1,200 HP. The greatest amount of work done in one day has been five hundred and eighty-five rails, or about 140 tons. These vary in length from 7.32 to 8.53 metres. The weight is 32.3 to 33.1 kilograms per metre. In testing the finished work, three rails out of every thousand are taken and cut into three parts. One part of each is subjected to a bending test by loading it with 17.25 tons midway between bearings 1 metre apart. The load must be carried for five minutes without producing a deflection greater than 3 millimetres, or a permanent set of more than 2 millimetres. The other two parts of the same rail are cooled in a mixture of ice and salt to -18° Centigrade, when they must receive two blows from a tup 490 kilograms falling 2.5 metres, supported on a bearing 1 metre apart, as before, without breaking. If three out of the nine samples fail in these tests, the whole batch is rejected.

The charges for projectiles consist of about 67 per cent. of Bessemer and other steel scraps, 5.4 per cent. of pig iron, 11.4 per cent. of Spiegel and ferro-manganese, and 9.1 per cent. of silicon manganese alloy. The metal is cast in chills, and the projectiles are oil-tempered, about 20 per cent. being broken in the process.

Latterly the increased customs duty has prevented the use of good foreign scrap and pig iron, and an attempt has been made to adopt the basic process for inferior material. The following changes have been tried:—

	Per cent.
Iron ore	6.7
Lime	6.7
Cleveland pig	25.0
Old ingot moulds	4.5
Scrap	44.5
Hematite pig	6.7
Spiegel	5.4
Ferro-manganese	0.5
	<hr/> 100.0 <hr/>

The iron ore was a quartzose specular iron from Stripa, in Sweden, containing about 48 per cent. of iron. The Cleveland pig

contained 1·62 per cent. of phosphorus, the broken ingot moulds 0·7, and the scrap 0·3 per cent.

The furnace bottom was covered with a mixture of dolomite and coal tar, which burns to a very hard mass. About two-thirds of the lime and iron ore were first charged with the pig iron and a part of the scrap, the remainder of the former and the latter followed at short intervals. When a test of the metal, after hammering and cooling in water, can be bent double without breaking, the hematite pig is added, and when it is completely incorporated, and a fresh test is capable of bearing from 5 to 8 blows of a 9·4-kilogram sledge, the Spiegel and ferro-manganese are added. Care must be taken before each addition to the charge to remove the highly phosphuretted slag. The finished ingots contain only 0·06 per cent. of phosphorus.

H. B.

On the several Systems of Units for Electric and Magnetic Measurements. By R. CLAUSIUS, Hon. M. Inst. C.E.

(Verhandlungen des naturhist. Vereins der preuss. Rheinlande und Westfalens. Bd. xxxix. 1882.)

There are two systems of units for electrical measurements—the electrostatic and the electro-dynamic. In describing the derivation of these systems from the fundamental units of mass, length, and time, the Author in general follows Maxwell's Treatise ("Electricity and Magnetism"); but points out an error in the dimensions of the electrostatic unit of magnetic quantity. This is deduced from the electrostatic unit of electricity by means of Ampère's theory. Consider two equal plane figures of unit area bounded by closed curves, in parallel planes, indefinitely near each other. Let currents of unit strength flow in opposite directions round these curves, and denote the perpendicular distance between the planes by $\epsilon \pi$, where π is the unit of length, and ϵ a numerical quantity. Then by Ampère's proposition such a system produces the same effects as if the figures had been uniformly coated with an amount $\frac{m}{e}$ of magnetic matter of opposite signs, m being the unit of magnetic quantity; and the magnetic moment is equal to the product of the current intensity and the area. Hence—

$$\frac{m}{\epsilon} \epsilon \pi = e \pi^2 \tau^{-1}$$

$$\text{or} \quad \frac{m}{e} = \pi \tau^{-1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Now the dimensions of e , the electrostatic unit of electricity, are $\mu^{\frac{1}{2}} \pi^{\frac{3}{2}} \tau^{-1}$ and of m , the electro-dynamic unit of magnetic

quantity $\mu^{\frac{1}{2}} \pi^{\frac{3}{2}} \tau^{-1}$, μ denoting the unit of mass, and τ the unit of time.

$$\text{Hence } m_e = \mu^{\frac{1}{2}} \mu^{\frac{1}{2}} \tau^{-2} \dots \dots \dots (2)$$

$$\text{and } e_e = \mu^{\frac{1}{2}} \pi^{\frac{1}{2}} \dots \dots \dots (3)$$

Maxwell derives his units from the equations

$$m c = \frac{\pi^2 \mu}{\tau^2} \text{ and } \frac{e}{c} = \tau$$

where c is the unit of current.

$$\text{Hence } e m = \mu \pi^2 \tau^{-1},$$

$$\text{therefore } e_e = \mu^{\frac{1}{2}} \pi^{\frac{1}{2}}.$$

But the equation is only applicable to the electro-dynamic system, and when applied to the electrostatic system gives the wrong result¹

$$e, m_e = \mu \pi^2 \tau^{-1},$$

and therefore

$$m_e = \mu^{\frac{1}{2}} \pi^{\frac{1}{2}}.$$

After defining the other electrical units, the Author compares the two systems. The force between two electrostatic units of electricity at unit distance is the unit of force, and is therefore equal to $[e^2 \pi^{-2}]$. Let $k [m^2 \pi^{-2}]$ represent the force between two electrostatic units of magnetic quantity at unit distance. This can be written $k [\pi^2 \tau^{-2}] [e^2 \pi^{-2}]$. But the last factor is the unit of force, and the whole expression is a force; hence k is the reciprocal of the square of a velocity, called by the Author the critical velocity, and denoted by K . The force between two electrostatic units of magnetic quantity at unit distance is therefore $[\pi^2 \tau^{-2}] [K^{-2}]$ of a unit of force, but the force between two electro-dynamic units of magnetic quantity at unit distance is the unit of force; hence, since the forces vary as the squares of the quantities, the

¹ This result of Clausius has given rise to considerable discussion. (*Vide* "Philosophical Magazine," June 1882, p. 427.) The equation deduced from Ampère's theory may be written: magnetic pole \times length = $k \times$ current \times area, where k is a constant. Clausius defines his unit of magnetic quantity or pole by making $k = 1$; but in Maxwell's theory k is a physical quantity depending on the medium in which the current is placed. This quantity is called the magnetic permeability, and is of dimensions $\tau^2 \pi^{-2}$. Hence Maxwell obtains his result $\mu^{\frac{1}{2}} \pi^{\frac{1}{2}}$ for the dimensions of magnetic quantity. If the unit of magnetic quantity be determined by the consideration of the force which a current passing through the coil of a galvanometer exerts upon either pole of the needle, or from the electromotive force produced in a conductor moving in a magnetic field, results consistent with Maxwell's are obtained.

ratio between the magnetic units is as K to $[\pi \tau^{-1}]$. This can be expressed by the equation

$$\frac{v. s. [m_d]}{[m_s]} = \frac{[m_d]}{v. d. [m_s]} = \frac{K}{\pi \tau^{-1}},$$

where the prefix *v. s.* denotes that the electro-dynamical unit is expressed in electrostatic measure, and *v. d.* that the electrostatic unit is expressed in electro-dynamic measure. By means of the former equations this equation gives

$$m_s = \mu^{\frac{1}{2}} \pi^{\frac{5}{2}} \tau^{-2}; \quad m_d = \mu^{\frac{1}{2}} \pi^{\frac{3}{2}} \tau^{-1}.$$

From equation (1)

$$[e_s] = [m_s] [\pi^{-1} \tau]; \quad [e_d] = [m_d] [\pi^{-1} \tau].$$

Hence

$$v. d. [e_s] = v. d. [m_s] [\pi^{-1} \tau]; \quad v. s. [e_d] = v. s. [m_d] [\pi^{-1} \tau],$$

and
$$\frac{v. s. [e_d]}{[e_s]} = \frac{[e_d]}{v. d. [e_s]} = \frac{K}{[\pi \tau^{-1}]},$$

and
$$e_s = [\mu^{\frac{1}{2}} \pi^{\frac{3}{2}} \tau^{-1}]; \quad [e_d] = [\mu^{\frac{1}{2}} \pi^{\frac{1}{2}}].$$

The units of resistance, current, capacity, and electromotive force are similarly deduced.

As the Paris Electrical Congress has decided to give the name of Ampère to the practical unit of current,¹ the Author proposes to reserve the name Weber for the electro-dynamical unit of magnetic quantity. The system of units in practical use is then

Weber	.	.	$[m_d] = g r^{\frac{1}{2}} c m^{\frac{3}{2}} s^{-1} 10^8 = p^{\frac{1}{2}} q^{\frac{3}{2}} s^{-1}$
Coulomb	.	$[e_d] = g r^{\frac{1}{2}} c m^{\frac{1}{2}} 10^{-1} = p^{\frac{1}{2}} q^{\frac{1}{2}}$	
Ampère	.	$[i_d] = g r^{\frac{1}{2}} c m^{\frac{1}{2}} s^{-1} 10^{-1} = p^{\frac{1}{2}} q^{\frac{1}{2}} s^{-1}$	
Volt	.	$[E_d] = g r^{\frac{1}{2}} c m^{\frac{3}{2}} s^{-2} 10^8 = p^{\frac{1}{2}} q^{\frac{3}{2}} s^{-2}$	
Ohm	.	$[R_d] = c m s^{-1} 10^9 = q s^{-1}$	
Farad.	.	$[C_d] = c m^{-1} s^2 10^{-9} = q^{-1} s^2$	

In the second column the unit of mass p being taken as $1^{\text{gr}} 10^{-11}$; the unit of length q as $1^{\text{cm}} 10^9$, and the unit of time remaining the second.

The Author concludes by describing a new system, which he calls the critical system. The ratio of each unit in the dynamical system to the corresponding unit of the statical system is equal to the ratio, or a power of the ratio of the critical velocity to the unit of velocity; hence, if the unit of velocity be chosen equal to the critical velocity, this ratio will in each case be unity. It is convenient to keep the second as the unit of time. The unit of length (λ) is therefore the space passed over in a second by a

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. lxvii., p. 522.

point moving with the critical velocity; and is equal approximately to 30 quadrants of the meridian. The unit of mass (μ) is chosen, so that the units of currents and quantity retain the same value in the new system as in the practical system. Since

$$[e_s'] = p^{\frac{1}{2}} q^{\frac{1}{2}} \text{ and } [i_s] = p^{\frac{1}{2}} q^{\frac{1}{2}} s^{-1},$$

and $[e_s] = \lambda^{\frac{1}{2}} \mu^{\frac{1}{2}} \text{ and } [i_s] = \mu^{\frac{1}{2}} \lambda^{\frac{1}{2}} s^{-1}$

if the values of the units remain the same

$$\mu = p \frac{q}{\lambda}.$$

This make μ approximately equal to $\frac{1}{3} 10^{-12}$ cm. The critical system is then

$$[m_s] = v. d. [m_s] = \mu^{\frac{1}{2}} \lambda^{\frac{3}{2}} s^{-1} = \frac{\lambda}{q} \text{ Weber.}$$

$$[e_s] = v. d. [e_s] = \mu^{\frac{1}{2}} \lambda^{\frac{1}{2}} = 1 \text{ Coulomb.}$$

$$[i_s] = v. d. [i_s] = \mu^{\frac{1}{2}} \lambda^{\frac{1}{2}} s^{-1} = 1 \text{ Ampère.}$$

$$[E_s] = v. d. [E_s] = \mu^{\frac{1}{2}} \lambda^{\frac{3}{2}} s^{-2} = \frac{\lambda}{q} \text{ Volt.}$$

$$[R_s] = v. d. [R_s] = \lambda s^{-1} = \frac{\lambda}{q} \text{ Ohm.}$$

$$[C_s] = v. d. [C_s] = \lambda^{-1} s^2 = \frac{q}{\lambda} \text{ Farad.}$$

Though this system is of no practical use, since the critical velocity is not sufficiently accurately known, it is of theoretical value from the agreement of the electro-dynamic and electrostatic units.

E. H.

Transport and Distribution of Energy by Electricity.

By MARCEL DEPREZ.

(La Lumière Électrique, December 1881, p. 309.)

The Author begins his Paper with a simple and exact explanation of the terms and principles employed by electricians. Thus in explaining what is meant by the strength of a current, he describes the electro-chemical laws of Faraday and Grove's gas battery; and in his account of electromotive force and resistance he describes the British Association units. The Author then considers the transport of energy, in the case of a battery whose electromotive force is E , from which wires proceed to a distant place where there is a decomposing cell of electromotive force e ; then if I is the strength of the current, he finds that (1) the positive chemical work representing the total work given out is expressed by EI ; for a given strength of current it is then proportional to E . (2) The negative chemical

work is expressed by eI ; for a given strength of current it is then proportional to e . (3) The efficiency is equal to the ratio of $E:e$. (4) The chemical work given out, the work utilised and the efficiency, remain constant whatever be the distance of transport, provided that the electromotive forces are proportional to the square root of the resistance. The Author now takes up the transport of heat-energy, describing the law of Joule and comparing the chemical action in a cell with the heat developed in it; and he shows that if it is wanted to transport energy to a distant place where it is to assume the form of heat, and if E is the electromotive force of the machine or battery to which energy is given, and if e is the electromotive force in the portion of the circuit in which heat is to be developed, four results are deduced, which are exactly the same as those which he obtained in speaking of chemical energy. The question of the transport of mechanical energy is next considered, and the same four results arrived at, E being the electromotive force of his generator of electricity, e being the back electromotive force of the motor at the distant place. Besides getting out these four results, he arrives at many conclusions which are of less importance. For instance, when a motor is doing work, the same amount of work may be effected for two different values of current strength. He now enters into the laws which govern the actions of magneto- and dynamo-electric machines. One of these laws which the Author has arrived at by experiments, which he describes at some length, is this. The turning moment or "torque"¹ produced in a given machine is proportional to the strength of the magnetic field and to the strength of the current, and is independent of the velocity of the armature. The numerical application of the mathematical formulas used in the early part of the Paper to the supposition of certain English and American philosophers, that a 13-millimetre ($\frac{1}{2}$ inch) wire of copper will suffice for the transmission of the energy of Niagara to New York, shows that the insulation of such a cable would be impossible. M. Deprez takes up a practicable case of transmission of mechanical energy, basing his calculations on the results of the experiments of Chatham, and he shows that it is feasible to transmit 10 HP. to a distance of 50 kilometres (31 miles) through a line of ordinary telegraph wire, 16 HP. being given to the arrangement and 6 HP. being wasted.

The remaining part of this Paper is devoted to the theory of the distribution of electric energy to a number of consumers, and begins with a graphical treatment of the theory of dynamo-electric machines. The relation between E , the electromotive force produced by a given machine, and I , the current, can be found experimentally for a given speed, and when this relation is shown by a

¹ Any force-system which can be equilibrated by a couple in the original and commonly specified, but commonly departed from, sense of the term is called a "Torque" by Professor James Thomson. The use of this new word will save much periphrasis.—J. P.

curve it is called the characteristic of the machine. For a new speed all the ordinates which represent different values of E have simply to be altered proportionately to the speed. If OE , OI , are the axes of co-ordinates, and OGH is the characteristic curve, then letting fall a perpendicular GF upon OI , GF is the electromotive force when OF is the current, and hence $\tan GOF$ is equal to the resistance. With only one characteristic for some given speed, it is easy to see how to find I and E for any given value of R , if the speed is different, without having to draw the new characteristic. The Author proceeds to show how to indicate on his diagram (1) the effect of a change of resistance of his machine; (2) the difference of potentials at two points of the circuit when the resistance between them is given. He shows the change in form of his characteristic when there is an initial magnetic field, the curve starting from a point in the production of the axis IO , namely, O' , and cutting OE in a part F , the part $O'F$ being quite straight. The result of the graphical expression of the necessity for a constant difference of potential between two points in a circuit, however the resistance between them may vary, is: (1) there must be an initial magnetic field produced in the dynamo machine, which shall be independent of the current in the circuit; and (2) the constant speed of the dynamo machine must be determined from the figure which has been drawn. When this is done a constant difference of potential can be established between two points, and however many consumers of electrical energy may join these two points by separate wires, each of them will receive just as much electricity as if the others had no existence. This adjustment is instantaneous and automatic.

M. Deprez now shows that, when energy is to be dispensed at various portions of a circuit which are all in series, it is practicable, by working the machine at a constant speed, which is measurable from the graphical demonstration, to cause a constant current to run through the circuit however the resistance of each portion of it may be made to vary. The machine in this case must be such that its field magnets form a shunt to the external circuit, and there must be an initial magnetic field which is independent of the currents. In conclusion the Author shows that as far as experiments have yet been carried they prove his graphical method of demonstration to be one which may be relied upon; and although he sees quite well the difficulties which have to be overcome before a general system of electric distribution can be successful, yet he feels that further applications of the graphic method will resolve them. He speaks specially of the use of accumulators in a distributive system as a problem still to be considered.

J. P.

On the Electric Transmission of Power to Great Distances.

By MARCEL DEPREZ.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. xciv., p. 434.)

The experiments hitherto made on electric transmission have been to short distances. In the applications at Noisiel the distance was 3 kilometres, the conductors having low resistance. The Author obtained with Gramme's machines, weighing 100 kilograms, and modified as indicated by him, useful work of 37 kilogrammetres, through a resistance of 786 ohms, representing a distance of 78·6 kilometres of ordinary telegraph wire, the efficiency being 25 per cent. This was effected without sparks at the brushes, the machine remaining quite cool, and without requiring special precautions for the insulation of the conductors.

E. F. B.

Notes on the Properties of Dynamo-Electric Machines.

By ELIHU THOMSON.

(The Journal of the Franklin Institute, December 1881, pp. 427-429.)

The Author describes experiments which illustrate the tendency of the cast-iron field magnets of his machine to prolong the current after the machine had stopped. Motion of about one hundred and fifty revolutions per minute was given to the machine, its circuit being closed. It was now suddenly stopped and the circuit at once broken, when a spark appeared at the break, and if the ends of the wires were held in the hands a smart shock could be felt. This after-current is due to the gradual loss of magnetism by the field magnet. A more curious effect, however, is produced by suddenly throwing off the driving belt when the machine is running at a moderate speed on closed circuit; the armature of his machine in this case rapidly comes to rest, and then, singularly, takes about three quarters of a turn in the opposite direction. This is due to the cause already mentioned.

The Author finds that when a single machine driven by power is connected with two others in multiple arc, so as to drive them as motors, the motors being of different sizes, and not being allowed to do external work, these motors acquire such different speeds as just enable the currents through them to be equal, and their back electromotive forces to be equal. The different electrical resistances of the two machines exert a modifying influence, no doubt; but this seems to count for little in comparison with the back electromotive forces. The effect of running the two machines in series as motors is very different. When so used, and with their shafts very free to turn, the larger, or one capable of pro-

ducing the highest counter-electromotive force to that of the generator, alone revolves, while the smaller remains at rest. If, however, the former or larger machine be made to perform mechanical work—that is, to furnish power—its running speed is, of course, retarded, and the other machine turns with a speed depending on the amount of work abstracted from its companion.

J. P.

Report of the Committee on the Precautions to be taken to obviate the Dangers that may arise from Systems of Electric Lighting.

(The Journal of the Franklin Institute, December 1881, pp. 401-408.)

This report describes simply the cause of the occurrence of a spark at any place where wires convey electricity to lamps, and deals rather with danger to buildings from fire than danger to the person from shocks. The recommendations of the committee are as follows:—1. That the conducting wires leading into and out of the building be suitably insulated throughout their entire extent, both to and from the machine producing the current. 2. That an inspection be made at suitable intervals to determine whether or not the insulation has been preserved intact. The insulation may become impaired by the following causes, viz.: by the wires being cut by the staples or hooks used in securing the conducting wires in position. By the wires being placed in positions subject to abrasion, either by chafing with another wire, or from any other cause. By the wires turning sharp bends, or by being sharply bent by any cause whatever. 3. That conductors formed of numerous short pieces of wire be avoided as far as possible, and that where their use is necessary the joined ends be made as secure as possible by wrapping, so as to prevent short arcs being formed at imperfect junctions, should the joined ends be partially separated from each other. 4. That the wires be not grounded; that is, that no attempt be made to cause the current to pass back to the machine through the earth, but that a continuous line of wire be provided through which the current shall so return. In order that this precaution may be effective, the wires should not be carried near metallic bodies like lines of shafting, nor gas nor water-pipes, because an accidental contact of the conductor with any of these would effectually ground that part of the wire. Where it is necessary that the wire cross such metallic bodies, it is advisable that the insulation be made better than usual at such junctions. 5. That the ready occurrence of cross contacts or short circuits be avoided as follows, viz.: that the conducting wires from different machines, or from different parts of the same machine, be kept as far apart as convenient, and never, except when necessary, be brought nearer together than the distance between the two binding-screws on any electric lamp used in the

circuit. That, therefore, the wire leading from the machine into the room to be lighted should leave the room as far as convenient from the place it enters. That the wires be securely fixed in position, and be not allowed to sag or bend in wide curves, except where it is necessary to permit the raising or lowering of the lamp. That judgment be exercised in selecting the portions of the building in which to run the wires. To secure, as far as possible, the absence of moisture, ceilings are to be preferred to walls or floors, the latter being highly objectionable unless the wires are placed under the flooring. As before stated, the location selected should be removed as far as possible from metallic conductors. Places least liable to be rendered partially conducting by moisture from any source should be selected, in which to run the wires. 6. That the conducting wires be of sufficient size to carry the most powerful current employed without dangerous heating. 7. To avoid the danger to life from the accidental discharge of the current through the body, the conducting wires should, in all cases convenient, be placed out of the reach either by choice of location or the use of heavy and guarded insulation. 8. That where lamps of the arc type are used they be covered with a globe of glass, and that the lower end of such globes be furnished with a cup or pan for retaining any heated fragments. The committee believe that if these precautions be taken, electric lighting can be thoroughly safe and reliable, and that all dangers attending its use can be entirely obviated.

J. P.

Experiments on the Quantity of Gas Produced and its Illuminating Power at various Periods of Carbonization.¹

By ALBERT ELLISSEN.

(Compte rendu de la Société Technique de l'Industrie du Gaz en France, 1881, p. 345.)

The Author has recorded the results of experiments made with a bench of seven retorts of the Paris Gas Company's type, with charges of 100, 110 and 120 kilograms of coal. The details are given in two tables, one showing the results of 4 hour-charges, and the other of 4 hour 48 minute-charges (or five charges per 24 hours). Observations were made at the end of each quarter of an hour, and the gas produced was divided into two parts, one for lighting purposes and the other for heating and motive power. The gas produced during the first quarter of an hour of the charge was of low illuminating power, varying according to the moisture of the

¹ An account of these experiments was contained in a paper "On Gas Supply, both for Heating and Illuminating purposes," by Dr. C. William Siemens. F.R.S., read to the British Association of Gas Managers at Birmingham, June 14, 1881.

coal. This was included with the heating gas, and only the gas obtained after the first quarter up to $2\frac{1}{4}$ hours from the commencement was considered as illuminating gas.

The mean results obtained are summarised as follows:

4 HOUR-CHARGES of 110 kilograms.

(1.) Gas produced per 100 kilograms of coal carbonized—

	Cubic Metres. ¹
1st. From 0h. 15m. to 2h. 15m.	18·062
2nd. „ 0h. to 0h. 15m., and 2h. 15m. to 4h. 0m.	11·308
Total	<u>29·370</u>

(2.) Percentage of gas produced—

	Per Cent.
1st. From 0h. 15m. to 2h. 15m.	61·502
2nd. „ 0h. to 0h. 15m., and from 2h. 15m. to 4h. 0m.	38·498
	<u>100·000</u>

(3.) Average illuminating power of gas—

	Litres. C. Feet.
1st. From 0h. 15m. to 2h. 15m.	87·7 = 3·09
2nd. „ 0h. to 0h. 15m., and from 2h. 15m. to 4h. 0m.	128·2 = 4·53
Calculated average of the mixed gas	103·3 = 3·65
Average of the mixed gas determined by observation	105·7 = 3·73

4 HOUR 48 MINUTE-CHARGES of 110 kilograms.

(1.) Gas produced per 100 kilograms of coal carbonized—

	Cubic Metres.
1st. From 0h. 15m. to 2h. 15m.	20·388
2nd. „ 0h. to 0h. 15m., and from 2h. 15m. to 4h. 48m.	9·741
Total	<u>30·129</u>

(2.) Percentage of gas produced—

	Per Cent.
1st. From 0h. 15m. to 2h. 15m.	67·673
2nd. „ 0h. to 0h. 15m., and from 2h. 15m. to 4h. 48m.	32·327
	<u>100·000</u>

(3.) Average illuminating power of gas—

	Litres. C. Feet.
1st. From 0h. 15m. to 2h. 15m.	101·1 = 3·57
2nd. „ 0h. to 0h. 15m., and from 2h. 15m. to 4h. 48m.	132·4 = 4·68
Average of the mixed gas	111·2 = 3·93

From these experiments the Author is of opinion that it would be possible to divide the products of carbonization into illuminating gas and gas for heating and motive power. In this case, instead of producing, as usual with 4-hour charges, an average of about 30 cubic metres per 100 kilograms of coal, of gas with an average

¹ 1 cubic metre = 35·316 cubic feet.

illuminating power corresponding to a consumption of 105 litres of gas for a light equal to a Carcel lamp burning 42 grammes of oil per hour, there would be obtained :

(1.) About 18.5 cubic metres of gas of an illuminating power equal to 57 litres per Carcel.

(2.) About 11.5 cubic metres of heating gas of an illuminating power equal to 125 litres per Carcel,

or per 100 cubic metres of gas.

61.50 cubic metres of lighting gas.
26.50 " " of heating gas.

This division could be effected by receiving in separate holders the gas produced during the first quarter of an hour of the charge, together with that produced during the last $1\frac{1}{4}$ hour, and reserving for lighting purposes the gas obtained after the first quarter of an hour up to $2\frac{1}{4}$ hours from the commencement of the charge.

C. G.

NOTE.—The French standard of illuminating power is expressed by the number of cubic litres of gas consumed to produce a light equal to a Carcel lamp consuming 42 grams of Colza oil per hour. This Carcel lamp gives a light equal to about $9\frac{1}{2}$ candles of the English standard, which is a sperm candle consuming 120 grains of sperm per hour.—C. G.

On the Lighting of Railway Carriages, Steamboats, Ships, Tram-cars, and Marine Buoys by Compressed Coal Gas.

By A. GÆLZER.

(Compte-rendu de la Société Technique de l'Industrie du Gaz en France, 1881, p. 388.)

The lighting of railway carriages, steamboats, &c., by gas, has become a question of considerable importance. The numerous inconveniences attending lighting with oil render it unnecessary to point out the superiority of gas, whether on account of its greater illuminating power, as compared with the well-known smoky oil lamps, or for its cleanliness and economy.

Taking, for an estimate, a train composed of ten carriages, each lighted by four lamps for eight hours per day, the cost for one year's lighting with oil at 5 centimes ($\frac{1}{2}d.$) per lamp per hour would be :

	Francs.
$10 \times 4 \times 8 \times 5 \times 365$	= 5,840
with gas at 1.05 franc per cubic metre, or 23s. $9\frac{1}{2}d.$ per 1,000 cubic feet.	
$10 \times 4 \times 8 \times 2.75 \text{ centimes} \times 365$	= 3,212
The saving would be	= 2,628

The oil is here taken at a price lower than it can be obtained at; generally it would vary between 6 and $7\frac{1}{2}$ centimes per hour; while, on the contrary, the gas is estimated at a higher rate than it has cost during several years of use, and a profit is added for its manufacture.

Coal-gas loses a considerable portion of its illuminating power by compression, its use is difficult on account of the necessarily limited size of the reservoirs, the weight of the apparatus, and the necessity of placing them on the roofs of the carriages, thus decreasing their stability. For these reasons it is proposed to substitute oil gas, which has an illuminating power $3\frac{1}{2}$ times that of ordinary gas, may be kept for years without its illuminating power being diminished, and which leaves no deposits, even in pipes of small diameters.

The apparatus used for making the gas consists of four pairs of retorts, each pair built in a bench with a furnace; the retorts placed one over the other and connected together at one end. The oil is contained in reservoirs placed above the benches, it runs in a fine stream through a funnel into an iron tray in the retort, where it remains until evaporated. This tray enables the residue to be easily removed, and prevents the cold oil falling on the heated surface of the retort. The volatilization commences in the upper retort, and is completed in the lower one; the gas passes through a condenser and a purifier containing alternate layers of lime and saw-dust; it then passes to the meter, and from thence to a gas-holder, from which it is pumped, under pressure, into a reservoir. The gas obtained is quite permanent, of a high illuminating power, and does not leave any deposits, liquid or solid, in the pipes or elsewhere. The oil used is obtained from paraffin refuse, lignite or shale, the price of which is very moderate, and 100 kilograms (220 lbs.) of oil produce from 50 to 60 cubic metres (1,765 to 2,118 cubic feet) of gas, according to the quality of the oil.

The gas is pumped into a reservoir under a pressure of 8 to 10 atmospheres; from this reservoir pipes are conveyed to stand-pipes placed on the station platforms. For filling the carriage-reservoirs, a connection is made with the stand-pipes, and the gas is allowed to enter until a pressure of 6 atmospheres is obtained. In ten minutes ten carriages can be charged with the gas necessary for forty hours' consumption. A specially constructed governor is used to maintain an invariable pressure of the gas as consumed.

The reservoirs are placed underneath the carriages; they are from 2 to $3\frac{1}{2}$ metres in length, and 50 to 70 centimetres in diameter, according to the distances the carriages have to run; they are made of plates 5 to 8 millimetres thick, riveted together, and the joints and rivets carefully soldered, to render them perfectly tight. When it is necessary to place two cylinders under one carriage they are joined together by a pipe. The governor is connected with the cylinder by a pipe 6 to 7 millimetres in diameter, and another pipe, 8 to 9 millimetres in diameter, conveys the gas to the roof of the carriage. A tap on the outlet of the regulator admits of all the lights being extinguished if necessary. The lamps of each compartment are supplied by pipes branching from the principal one, each provided with a separate tap, so that each lamp can be lighted or extinguished singly. The lamps are similar to the ordinary ones, the body being of cast and the cover and chimney

of wrought iron. The burners are carefully-made steatite fish-tail burners.

This system of lighting may also be used for marine buoys, the cost of lighting which would not exceed 50 to 75 centimes per twenty-four hours, and they would only require filling two or three times per annum.¹

By means of such buoys navigation would become safe during the darkest night, the necessity for which is becoming imperative, on account of the ever-increasing traffic with large steamers, and, to promote the greatest development of commerce, it is desirable to render navigation as safe by night as by day.

C. G.

On the Velocity of Cooling of Gases at High Temperatures.

On the Specific Heat of Gases at High Temperatures.

On the Temperature of Combustion and on the Dissociation of Carbonic Acid and of the Vapour of Water.

By MESSRS. MALLARD and LE CHATELIER.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. xciii., pp. 962, 1014, 1076.)

The Authors employed the Bunsen process, detonating the explosive mixture in an iron cylinder, measuring the resulting pressure by means of a Bourdon manometer, from the moment of explosion down to that of complete cooling, whereby, knowing the pressure and volume at 0°, the temperature can be calculated when dissociation does not take place. The experimental process employed furnished the means, as it imposed the necessity of studying the velocity, of cooling, which is represented between 1,800° and 300° Centigrade by the following formula for carbonic acid—

$$v = k w_0^{-0.75} (e^2 + 200 e),$$

in which w_0 is the pressure of the gas when it has returned to that of the surrounding air, e the variable excess of the temperature of the gas above this, k is an independent coefficient which equals 0.00003381 under the circumstances of the experiments referred to.

This formula, put into another form, agrees with the experiments of other physicists as recorded by their formulæ under lower degrees of pressure, and therefore of temperature. When carbonic oxide, nitrogen or oxygen are mixed with the carbonic acid, the law of cooling is the same, k alone varying. Above 1,800° and 1,900° the formula ceases to hold good, proving that dissociation sets in at that temperature.

In operating upon the detonating mixture of hydrogen and oxygen the velocity of cooling follows a completely different law,

¹ Compressed gas has been successfully used for lighting buoys in England.

showing a diminution of pressure so rapid that this falls in a quarter of a second from 5 metres of mercury to atmospheric pressure, and presenting a practical interest, in that it proves that the condensation commencing on the cylinder at $3,000^{\circ}$, continues down to 0° , following throughout the same law.

Knowing the law of cooling under given circumstances, the loss of heat from the moment when combustion commences to that when the indicator of the manometer marks the maximum, can be determined, and hence the mean specific heat at constant volume at temperatures below those of dissociation. For carbonic acid in which the sum of the elements $C+2O=44$, the mean specific heat is 12.6. It increases up to $2,000^{\circ}$ with the temperature, but the rate of increase diminishes. The following formula, when $t < 2,000^{\circ}$, gives the results of several concordant experiments with carbonic acid, the specific heat equals $6.3 + 0.00564 t - 0.00000108 t^2$. In putting variable proportions of nitrogen, oxygen, or carbonic acid, in place of one another, the temperature of combustion remains constant, and hence the relation of the specific heats of these substances is the same at $2,000^{\circ}$ as at 0° . The specific heat of the vapour of water $H_2+O=18$ is found to be 11.5 at 1600° , and is given by the formula $C=5.91+0.00376 t-0.000000155 t^2$. The determination of the specific heats at high temperatures allows the approximate resolution of the two problems, the temperature of combustion of the principal inflammable gaseous mixtures, and that of dissociation of compound gases.

The following two Tables give the calculated and observed temperatures of the detonating mixtures respectively of hydrogen and carbonic oxide, with various mixtures of foreign gases. They refer to combustion in a closed vessel; whilst under the conditions of ordinary combustion, as the gases expand freely the resulting temperature would be much lower, although, as the variation of the specific heat at constant pressure is unknown, it is not yet possible to determine how much lower.

HYDROGEN and OXYGEN.

Volumes of Foreign Gases for 1 volume of detonating Mixture.					Temperatures.	
Hydrogen.	Oxygen.	Nitrogen.	Total Volume of Permanent Gases.	Vapour of Water.	Observed.	Calculated.
..	0.49	..	0.49	0.02	2,740	2,660
0.52	..	..	0.52	0.02	2,680	2,610
..	0.99	..	0.99	0.03	2,190	2,230
0.96	..	..	0.96	0.06	2,190	2,230
..	..	1.28	1.28	0.03	2,060	2,050
2.07	..	..	2.07	0.04	1,750	1,750
..	1.96	..	1.96	0.04	1,750	1,790
..	0.15	1.86	2.01	0.05	1,770	1,760
2.84	..	1.33	4.17	0.07	1,240	1,220
..	0.72	3.99	4.71	0.09	1,140	1,140

CARBONIC OXIDE and OXYGEN.

Volumes of Foreign Gases for 1 volume of Detonating Mixture.						Temperatures.	
Car- bonic Oxide.	Oxygen.	Nitro- gen.	Total Volume of Permanent Gases.	Carbonic Acid.	Vapour of Water.	Observed.	Calculated.
..	1·61	0·05	2,025	2,040
..	1·82	0·04	1,580	1,860
..	0·08	2·01	0·04	1,680	1,690
..	0·06	2·11	0·03	1,600	1,660
..	..	1·27	1·27	..	0·05	2,270	2,260
..	..	2·11	2·11	..	0·04	1,900	1,860

E. F. B.

On the Rate of Propagation of Explosive Phenomena in Gases.

By Messrs. BERTHELOT and VIELLE.

On the Explosive Wave. By — BERTHELOT.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. xciv., pp. 101 and 149.)

The method employed consisted in filling with an explosive mixture a tube of great length (about 40 metres), the ignition was produced at one extremity by means of an electric spark, and two electric currents, passing at measured intervals apart, were interrupted by means of the passage of the flame itself. These currents are transmitted by very narrow bands of tin, glued on paper, and pressed between insulating material, normally to the direction of the flame ; a grain of fulminate of mercury, weighing 0·01 gramme, which detonates on contact with the flame, destroys the band and stops the current. The intervals of time were measured by means of Le Boulengé's chronograph, an instrument which measures with precision one-twenty thousandth of a second.

Experiments were made, 1st, on the arrangement of the tube; 2nd, on its material; 3rd, upon it open and shut; 4th, on its length; 5th, on the initial pressure of the gaseous mixture; 6th, on the composition of the mixture, which was varied by modifying the nature of the combustible gas, and by introducing inert gas.

1. The tube first experimented on was of lead, straight and horizontal, 42·45 metres long and of 5 millimetres internal diameter, filled at atmospheric pressure with a detonating mixture of oxygen and hydrogen. After each experiment the tube was thoroughly dried. The mean velocity obtained was 2,861 metres per second. The tube was then bent into a series of horizontal parallel lines, in effecting which its length was increased by 0·7 metre. The velocity was now found to be 2,788 metres per second.

2. The Authors had some doubt of the accuracy of the results on account of the unexpected velocity attained, which was intermediate between the velocity of sound in the detonating gaseous mixture and in the metal constituting the tube. Thinking the explosion of the fulminate may have been caused by some vibratory movement of the metallic tube itself, a tube of caoutchouc was next employed, 40·109 metres long and 5 millimetres internal diameter, and thick enough to support variation of pressure without sensible deformation. The mean velocity was found to be 2,810 metres per second. Glass tubes of 1·5 millimetre diameter, 43·34 metres in total length, were next used, and the mean velocity found to be 2,341 metres per second. Thus, as with sound, the velocity diminishes with diminution of the diameter of the tube.

3. Three series of experiments were made. When the distant orifice alone was left open the velocity was 2,645 metres per second; when the near end was open, 3,052 metres per second; when both were open, 2,766 metres per second; the mean velocity was 2,821 metres per second, and the Authors consider them all as sensibly equal.

4. With a mixture of H_2 and O, when the interruptors were 40 metres apart in the caoutchouc tubes, the mean velocity was 2,810 metres per second; when 30 metres apart, 2,704. With a mixture of CO and O, the distances being respectively 40·059, 29·982 and 20·092 metres, the mean velocities were found to be 1,089, 1,130 and 1,185 metres per second. The variations are not considered other than errors of observation.

5. The pressures were varied in the ratio of about 1 to 3. The caoutchouc tube was used. With H_2 and O, the pressures being 0·56, 0·76, 1·26 and 1·58 metre of mercury, the velocities were found to be 2,763, 2,800, 2,776, and 2,744 metres per second; with a mixture of CO and O, with pressures 0·57, 0·76, 0·834, 1·56, the velocities were 1,120, 1,089, 1,072, and 1,132 metres per second; and the results prove that the velocity is, as in sound, sensibly independent of the pressure.

6. The velocity is different with different detonating mixtures—with H_2 and O 2,810, with CO and O 1,089; with 55 per cent., 60 per cent., and 65 per cent. of air in the former mixture, the velocities were 1,439, 1,251, and 1,205 metres per second; whilst with 67·5 per cent. the explosion was not carried forward.

M. Berthelot, in the second memoir, remarks on these experiments, that they reveal the existence of a new species of undulatory movements, due to a combination of physical and chemical impulses. The properties of this new undulatory wave are:

1. That its velocity of forward motion is uniform. 2. That its velocity is due to the nature of the explosive mixture, and not to the nature of the material in which the explosion takes place. 3. The influence of diminution of diameter is to diminish the velocity. 4. The velocity is independent of the pressure. 5. The theoretic relation which should exist between the velocity of the explosive wave and the chemical nature of the gas transmitting it

is difficult to establish this velocity depending upon temperatures, and these not being the same in the combustion of the two different systems. The Author, however, gives the following formula after Clausius:—

$$c = 29.354 \sqrt{\frac{T}{\rho}} \text{ metres,}$$

where T is the absolute temperature of explosion and ρ the density of the gas with respect to air, which is found to agree closely with the velocities obtained in the experiments cited.

It would thus appear that in the act of explosion a certain number of gaseous molecules are shot forward with a velocity corresponding to the maximum temperature developed in the chemical combination, and the movement is propagated from section to section with a velocity identical or comparable with that of the molecules themselves. Things occur otherwise when the system has time to lose a portion of its heat by communication to other gases, or to neighbouring bodies not susceptible of the same chemical transformation. Such is, no doubt, the difference existing between ordinary burning and detonation proper.

E. F. B.

The Flame of the Bunsen Burner.

(Dingler's Polytechnisches Journal, Jan. 1882, p. 87.)

According to Wibel the flame of a Bunsen burner, which, by the admixture of air, is rendered non-luminous, becomes again illuminating if a tube of platinum be inserted in the mouth of the burner and heated. In Liebig's "Annalen," 1881, vol. ccvii. p. 167, R. Blochmann shows that the heating of the platinum tube acts partly like a closing of the air-openings, and at the same time alters the chemical constitution of the mixed air and gas, already rendered poorer in oxygen by the arrested flow of air. The gas with which he experimented at Königsberg possessed the following constitution —

Hydrogen H	52.75
Marsh gas C H ⁴	35.28
Olefiant gas C ² H ⁴	2.01
Propylene C ³ H ⁶	0.72
Benzol vapour C ⁶ H ⁶	0.66
Carbonic oxide C O	4.00
Carbonic acid C O ²	1.40
Nitrogen N	3.18
	<hr/>
	100.00
	<hr/>

When 38.7 per cent. by volume of this gas was mixed with 61.3 per cent. of air, the mixture gave the following analysis No. I., and

after being conducted through the heated platinum tube the analysis was as No. II.

	No. I.	No. II.
Hydrogen H	20.41	0.57
Marsh gas $C H_4$	13.65	12.54
Olefiant gas $C^2 H^4$	0.78	0.30
Propylene $C^3 H^6$	0.29	0.31
Benzol vapour $C^6 H^6$	0.25	0.19
Carbonic oxide $C O$	1.55	3.12
Carbonic acid $C O^2$	0.54	1.37
Nitrogen N	1.23	
Air { N	48.45	49.68
{ O	12.85	12.85
Water $H^2 O$ . . . . .	..	22.47
	<hr/> 100.00 <hr/>	<hr/> 90.55 <hr/>

In the heated platinum tube a combustion of the hydrogen takes place so far as the oxygen present in the mixture permits.

Wibel's experiment appears to show that the atmospheric non-luminous flame becomes luminous consequent only on the increase of temperature, but it proves nothing beyond the fact that a flame which by mixture with inert gases has lost its luminosity becomes again illuminating when the stream of gas is heated as it issues from the burner.

G. E. S.

On a Multiplying Anemometer Applicable to the Measurement of the Velocity of the Air in the Galleries of Mines, to Meteorological Observations, and to the Determination of the Velocity of Flowing Water. By Eng. BOURDON.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. xciv., p. 229.)

The result is effected by placing within the small portion of the section of a properly formed convergent-divergent tube (known as Venturi's) another similar tube, of dimensions sufficiently reduced so as to occupy its central portion. The diverging extremity of the smaller tube must be placed exactly on the converging section of the larger tube; a third tube may be introduced in the same way. For the measurements of velocities the truncated ends of the cones are connected with a manometer by means of a short cylinder enclosing them, with a sufficient interval to establish a communication with the interior of the short cylinder. The results of experiments with a two-tube anemometer give as a mean for the difference of height of the column of water raised by the direct pressure of the current, and the height due to the acceleration produced by the successive actions of the two tubes the ratio 1:20, which represents a velocity ratio of 1:4.5. In employing a three-tube anemometer the ratio of heights was 1 to 80, or 1:8.7 for velocity ratio.

The following are the advantages of this system of anemometer: that there is no delicate mechanism, it is easy to remove, and the property which it possesses of considerably amplifying the scale allows by use great exactness in experimental results.

E. F. B.

Fluviograph¹ with Indicator. By G. PETIT.

(Le Génie Civil, vol. L., p. 132.)

M. Moquery's fluviograph consists of a float following the rise and fall of the stream; a transmitter of the movements of the float by means of an electric current; a recorder, on the Morse system, inscribing the variations indicated by the transmitter; and an indicator showing the weir-keeper the water-levels to be regulated.

The float is simply a wooden cylinder, 1 foot in diameter, moving freely in a hollow zinc cylinder immersed in the stream, and pierced with small holes, which, whilst admitting the water, exclude eddies and surface ripples. An iron wire connects the float with the transmitter.

The transmitter consists of a pulley, $3\frac{1}{2}$ feet in circumference, on which very fine threads of a screw are formed, which receive the wire from the float. A spring makes the pulley turn and keeps the wire stretched when the float rises with the water, and the fall of the float turns the pulley in the opposite direction. A wheel on the same axis as the pulley is so formed as to make and break contact twenty times alternately in one revolution.

The recorder is merely a Morse recorder, unrolling at the rate of $2\frac{1}{2}$ inches per hour, which is sufficient in most cases. When the current comes by one wire, owing to the rise of the float, red dots are made; and when it comes by the other wire, owing to the descent of the float, the dots are blue. The variation of level is equal to as many times 2 inches as there are dots on the paper; and the actual level is indicated by the difference between the red and blue levels.

A graphic record of the changes is obtained by taking the times as abscissæ, and the variations in level as ordinates, and drawing a continuous line through the points thus obtained.

The indicator, which completes the apparatus, warns the weir-keeper of his duties. It consists of a hand moving round a dial, and so adjusted that it performs less than a whole revolution when the motion of the pulley is a maximum. The dial is so divided and figured that the hand points to the actual level of the water which the weir-keeper can thus read off. Two other movable hands are fixed to the dial, which can be set to the figures corresponding with the upper and lower limits of water-level at which

¹ Vide Minutes of Proceedings Inst. C.E., vol. liv., p. 297, and vol. lvii., p. 351.

the weir-keeper requires to be warned. When the indicative hand, moved by the motion of the float, reaches either of these hands, an electric bell warns the weir-keeper that the river has reached one of the limiting-levels, and that his presence is needed for altering the rate of discharge through the weir.

L. V. H.

A New Odontograph. By HUGO BILGRAM.

(Journal of the Franklin Institute, 1882, vol. cxiii., p. 1.)

The well-known condition for the correct gearing of toothed wheels is, that at the point of contact the normal, to two teeth which gear together, must pass through the point of contact of the pitch-lines. Contact of two teeth always takes place on a curve called the "path of contact"; this curve can be found for any given tooth form by dropping perpendiculars, from the contact point of the pitch-lines, on successive positions of the tooth profile; the *locus* of the feet of the perpendiculars is the required path.

It follows that the path of contact of any gear wheel depends solely on its own tooth-form, and is independent of the size of the mate, provided only the mate gears correctly.

If, therefore, a wheel A is to gear correctly with a wheel B, that part of the path of contact of A which is without the pitch-line must be congruent with the path of contact of B for points within the pitch-line, and *vice versa*. Similarly for a wheel C, if it also is to gear with A. If the wheels are to be "set wheels," B must gear with C; therefore the contact-path of B without the pitch-line must be congruent with the contact-path of C within the pitch-line; but the latter is congruent with the path of B within the pitch-line from the above condition of both gearing with A; it follows, therefore, that for set wheels the path of contact must consist of two congruent branches, one within and one without the pitch-line.

For that wheel of the set whose radius is infinitely great, the rack, the above condition for the path of contact requires a tooth-profile, which also consists of two congruent branches placed symmetrically about the pitch-line; this condition for the teeth of the rack of a set of wheels leads to the following construction of Odontograph.

A tooth-profile is chosen, consisting of two congruent branches meeting symmetrically and tangentially at a point in the pitch-line. A template of a portion of a rack (say one whole and two half-teeth) is filed up to suit the profile, and is attached by thin distance-pieces to a straight edge placed plumb under the pitch line. A disk, or portion of a disk, of a diameter equal to the pitch-diameter of the required wheel, is rolled along the straight edge, the disk carries a thin plate which projects between the straight edge and the rack template, and as the disk rolls successive positions of the tooth are scribed off on to the plate. The

envelope of the scribed lines gives the required tooth. A band of very thin steel, one end fastened to the rack and the other to the wheel-disk, may be used to prevent slipping.

The teeth thus formed will gear correctly, because the condition for the normal at contact is fulfilled, the contact-point of the pitch-lines being, by construction, the instantaneous centre of the relative motion. The wheels thus formed will also be set wheels, as, by construction, the condition for the path of contact is also fulfilled.

This Odontograph can be used for cycloidal, involute, or arbitrary tooth-profiles (having respectively, circular, straight, or arbitrary, paths of contact). For involute teeth the rack-profile is a straight line, which should be inclined at about 75° to the pitch-line. An arbitrary form is occasionally admissible, in order to obtain more "draft" in a bevel wheel near the pitch-line.

This Odontograph gives theoretically correct forms, not only for circular but also for elliptical or irregular-shaped wheels; it also gives a strengthening fillet at the bottom of the tooth of a size such that it will clear the points of the teeth of all wheels of the set.

The Author points out that the contact-path must in no place have a less inclination to the pitch-line than the corresponding element of the contact-path of a cycloidal tooth, the diameter of whose rolling-circle is equal to the radius of the smallest pinion; this prevents the smallest pinion being unduly undercut.

The Author treats of the wear of teeth. By means of the path of contact, points A' and B' may be found on one tooth which gear with points A and B on the other. The slip will be $AB - A'B'$, and the wear on each tooth will be proportional to $\frac{AB - A'B'}{AB}$

and $\frac{AB - A'B'}{A'B'}$ respectively. By dividing the teeth into small portions, the tendency to wear may be plotted on the tooth profile. Such a diagram shows that cycloidal teeth wear better than involute.

The concluding portion of the Paper discusses the practice, which occasionally obtains, of making the driving-teeth longer above the pitch line than the driven teeth; the Author shows that this is rational, and that it equalises somewhat the action of friction, which causes an inclination of the line of thrust out of the normal.

W. P.

On the Formation of Waves in Liquids. By P. A. CORNAGLIA.

(Journal de Mathématiques pures et appliquées, 1881, p. 289.)

Given a liquid mass agitated either by wind or other causes, numerous observations show that this movement under certain circumstances is propagated to considerable depths. Off the banks

of Newfoundland the reaction upon the waves is very sensible to ships approaching them, and exists at depths of 250 to 500 feet, showing that the agitation on the bank must be very powerful to produce sensible effects through a column of liquid of this great height and that it must extend even much lower.

On the other hand, this must cease at a given depth. Matter brought up by sounding shows that the most terrible Atlantic tempests have not force to produce at the bottom along the lines of submarine telegraph a sufficient undulation to affect the very delicate organisms deposited thereon, nor even to shift the grains of finest sand. Sometimes it is insensible at even less depths. Divers agree that ordinarily, even at moderate depths, the sea remains appreciably calm at the bottom, although it may be very much agitated on the surface.

Not far from the above named coasts, and therefore at inconsiderable depths, but sufficiently great to allow of anchoring, ships can hold on sufficiently well during a long night of tempest-riding from a floating anchor formed by a St. Andrew's Cross, on which is strongly fixed a stretched sail. This only requires the sinking of this species of anchor a few metres below the surface. The difference of pressure on the two forces is always equal to the weight of water displaced, whatever be the depth of the anchor and the resistances of the ship and the floating anchor in line of the connecting cable are opposed one to the other; from this it may be inferred that the floating anchor is in an envelope of liquid sufficiently tranquil to be able to hold it.

Whatever the causes, the agitation does not apparently extend beyond a certain limit, and this, contrary to the opinion of some who wish to generalise too much on certain observed facts, is not arbitrary but variable, and as it results from a force weakening in transmission it follows that it must diminish in a progressive manner as the depth towards the limit where it ceases altogether. This can be represented by a horizontal plane if the bottom is horizontal. If no exceptional circumstances intervene a wave in a short passage preserves very approximately the same form and the same rapidity, and the waves immediately adjacent are also equal, and all may be regarded as the same and uniform in velocity. Therefore, in a cross-section of the waves, the verticals comprised between the surface of the liquid and the limit of agitation are so much longer as the lowest point of the wave is lowest below its summit, and *vice versa* they are shortest as the wave summit is lowest above the hollow. Consequently, during the passage of a wave all the verticals pass successively all the phases of length of all the others comprised between the two extremities of the wave. And observation shows that the liquid has no real but only apparent motion. On the other hand it is continuous and incompressible, i.e., in a physicist sense (not changing sensibly its volume except under enormous pressure), and as each molecule above the limit of agitation never passes down to mix with those below, it follows that the heaping up towards the summit of the

wave must cause a corresponding diminution in the intervening hollow. Observation shows again that there is no confusion in the movement of the molecules; if it were otherwise, they would interfere one with the other, and soon the movement would cease, while facts show that on the contrary the undulations are propagated in a horizontal direction to great distances without diminishing much in height, and if other causes do not intervene they continue long after the cessation of the cause which produced them. From all this it may be concluded that the molecules oscillate within certain limits, vertically and horizontally, and that the oscillations decrease always in proportion that the molecules are at a greater distance from the surface. Col. Emy has explained very plausibly all the mechanism of waves. During the passage of a wave each trench of constant volume advances continually in the time occupied by the mounting of the wave, *i.e.* from the centre of the hollow to that of the wave crest and *vice versa*, in the descending period. These undulations decrease in profile until the plane is reached where the vertical oscillations up and down cease. The internal waves have the same amplitude, and are disposed in the same manner as those that are visible, always diminishing in height as they are lower, and the orbits in correlation with the waves are in the same time, but they become more and more small as they are found at greater depths. All this is in perfect accord with natural phenomena; in effect when the sea is sufficiently agitated, and the water is clear, if bodies are found in suspension, for example, branches of sea-weed, it will be seen that the bodies situate in the same vertical have all at the same instant a movement towards the surface when they are found in the trough, and towards the margin when they are found on the contrary in the wave due to the extent of the movements which are more pronounced upwards. One experiences the same in swimming, especially when floating, if at a depth equal the height of the person. Clearly this would not be so if at all depths the movements were not synchronous. It is incontestable that the vertical movement produces a corresponding horizontal one. On this subject the general scientific methods, pure and abstract, vigorously followed to the present time, have not arrived at results of real practical worth from the character of the algebraic expressions which have prevailed, styled by Lagrange "rebelles." Thus the engineer in questions of practice finds himself left to his personal experience more or less just as his observations are more or less complete and exact and his deductions more or less legitimate. Hence the interminable discussions characteristic of all questions affecting maritime works. By the aid of facts supported by observation, the natural phenomena can be followed step by step and close alongside.

If the producing forces are known, the determination of the movements sought for is obtained, and it is necessary to note that each effect is proportional to the force producing it, and *vice versa*, and that from the results of the wave itself, which is an effect, the

cause may be appreciated, *i.e.* the intensity and direction of the force which produces this wave, or which is capable of producing it in the same time as different movements which develop themselves in the liquid mass. This admitted, a given point is found simultaneously submitted to—

1st. The action produced by the displacement of the protuberance of liquid which forms the visible wave.

2nd. In the action of molecules which envelop it in their movements. In their reaction are included the effects of friction due to viscosity; but as facts show that the diminution of agitation is very gentle according to time and distance, friction must not be neglected, nor the reaction due to impulsion or reciprocal opposition that the moving molecules exert on account of the difference in their rapidity.

As the wave advances, each point of the liquid mass will traverse successively an imaginary vertical line passing through the lowest point of the trough of undulation. Observation shows that in the movement of waves, the displacements of molecules horizontally are always small in comparison with the half arc of the wave and the spaces traversed by it. In the lower strata of water, from the effect of gravity and the re-action of the bottom, the molecules of a lower wave parallel to that on the surface are subjected to hydrostatic pressure due to the depth of the liquid resulting in a flatter wave and trough than on the surface, decreasing in height of undulations to the plane, where the impinging force dies away or is extinguished.

When a wave passes the molecules belonging to the same level, *i.e.* to the same thin horizontal bed in the liquid in repose, they come one after another to take the same position in reference to the internal wave in such a manner that this wave moves parallel in a horizontal direction, whilst the molecules after the passage of an entire wave find themselves in the same position as before; it is thus that an apparent movement of the liquid has taken place. The wave advancing by a rectilinear horizontal movement, each point of its crest strikes successively all the molecules of the very thin continuous beds, for in rising and falling they are constantly carried against this crest in its passage to dispose themselves in their turn upon the respective wave to which they belong. Consequently each point of this crest or wave curve exercises an action on the molecules that are struck, and each of the molecules experience for an instant the action of the crest of the wave, this makes itself felt equally and spreads uniformly over all the molecules included in this passage in the direction in which the force is exerted. Thus a wave crest is nothing else than a succession of points, and the movement which an elementary arc of a wave exerts on one molecule during the whole time of its passage will be equal to the sum of the average movement of all these points, a mean force which makes itself felt on all the molecules comprised in the passage, because in this period of time all the points of this elementary arc pass close to these molecules.

The greater the inclination of the tangent to the crest, and the more the elementary arc of the crest in a given interval becomes great, so the number of the points are augmented precisely in proportion to the molecules in contact.

The internal waves must be like the visible wave mounting and descending during like periods consequent on the decisive preponderance of the vertical over the horizontal force, and thus is shown the great difference in the intensity of the two movements, and that composing the vertical determines chiefly the form of the waves. But as the vertical weight has a constant value for all the molecules situate at the same moment on the same vertical, the general passage of the waves should be the same for all (save the difference in their size) that are in relation with the greatest or least re-action of the molecules according to the different points of the liquid mass under consideration—for the rest, each effect being proportional to the cause producing it and *vice versâ*, one can consider the force which animates each molecule of the liquid mass by the effect of the displacement of the visible wave.

By these compressions and expansions the vertical liquid sections into which it is supposed the liquid mass when in repose is divided, expand and contract vertically during the passage of the wave, and correspondingly lessen and enlarge horizontally, and it follows pile themselves one on the other, producing thus the various molecular movements. Passing to the reaction of the molecules, it must be observed that if nothing else intervenes, all the points of the liquid mass on the same vertical will have in this direction the same velocity as being subject to the same force—but experience shows that the agitation, which is nothing else than movement, diminishes with the depth, and it follows that these points must have amongst themselves a varying vertical velocity. With this relative velocity the column strikes the liquid which is below it or sucks it up, and thus produces that mutual impulsions or retardation of movement which the molecules exert and which results in their re-action. Observation shows that this vertical velocity diminishes directly as the depth increases, and the molecular reaction increases on one side and diminishes on the other.

As the velocity diminishes with the actual force, *i.e.*, in proportion as the resultant of all the forces diminishes, and as the weight remains constant on all the points situate on the same vertical, it results definitively that the reaction of the molecules vertically is opposed to movement and increases with the depth, and the movement diminishes correspondingly until it dies away altogether.

Briefly, the duty to which the molecules are subject horizontally changes for all the vertical values passing from the crest to the lowest point of the hollow of the wave.

From all this, it results that the internal waves preserve a certain resemblance to the external ones, and that they are all found comprised between the surface and the plane where the agitation ceases. In other terms, in the horizontal direction as the vertical, the reaction of the molecules will be always negative during the

mounting period of the wave, and positive in the descending period, as one can see in observing the successive mode in which the vertical and horizontal sections arrange themselves, i.e., to say how they lengthen or shorten, and what the resultant effect is.

However great may be the depth, the velocity, however small, can never be extinguished altogether, and each molecule must sustain a certain pressure, horizontal and vertical. The effect of these forces is paralyzed more or less by the reaction of the molecules but cannot be entirely destroyed, because there is no reaction where there is no movement, which latter will not cease, save at infinite depths.

In reality, however, the movement ceases at the bottom on which the liquid reposes, as there, for want of elasticity, the result of the normal forces at the surface of the bottom will be destroyed, the molecules in contact therewith not detaching themselves, and the height of the internal wave becoming nil. The movement horizontally is proportional to the square of the height of the wave on which is found the supposititious molecule, the vertical direction is simply proportional to the first power of this same height.

Observation shows that a wave breaks when it arrives at depths scarcely equal to its own height, i.e., for want of depth it must have already suffered perturbations before arriving at this point—in other words to develop itself in a normal condition, as has all along been presupposed, the wave requires a greater depth to develop itself on than its own height.

These various positions are illustrated by a series of elaborate equations.

J. B. R.

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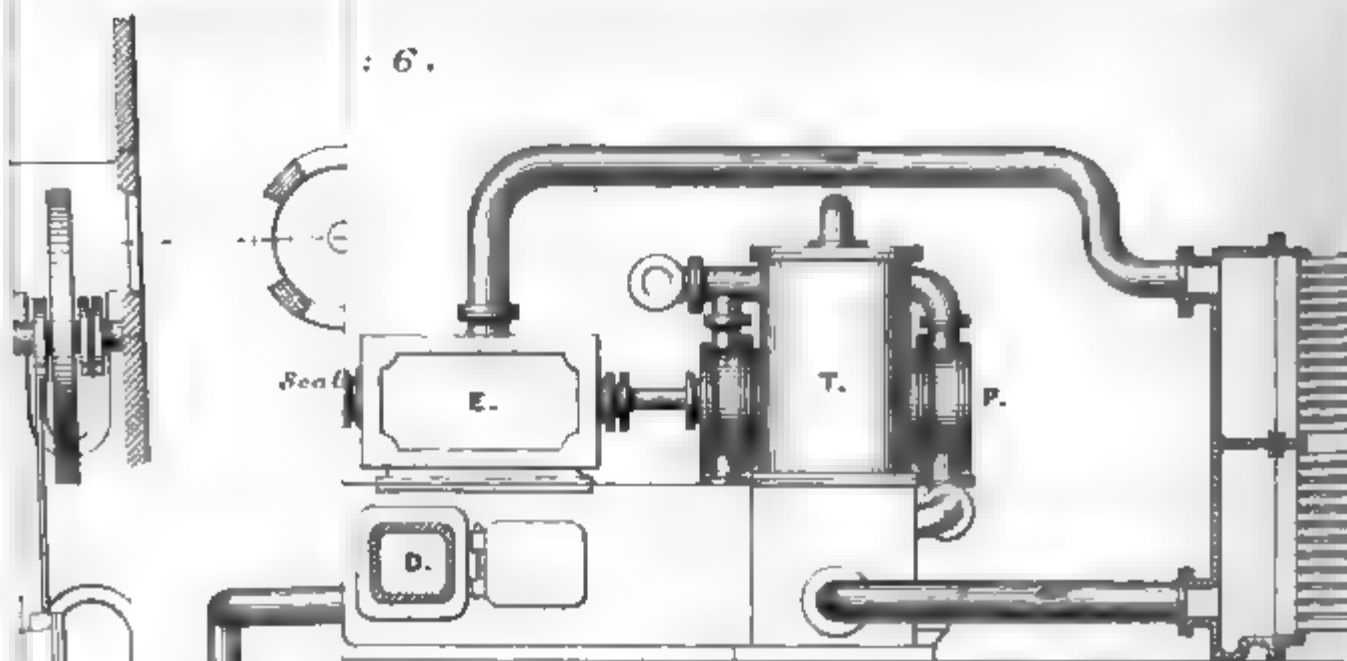
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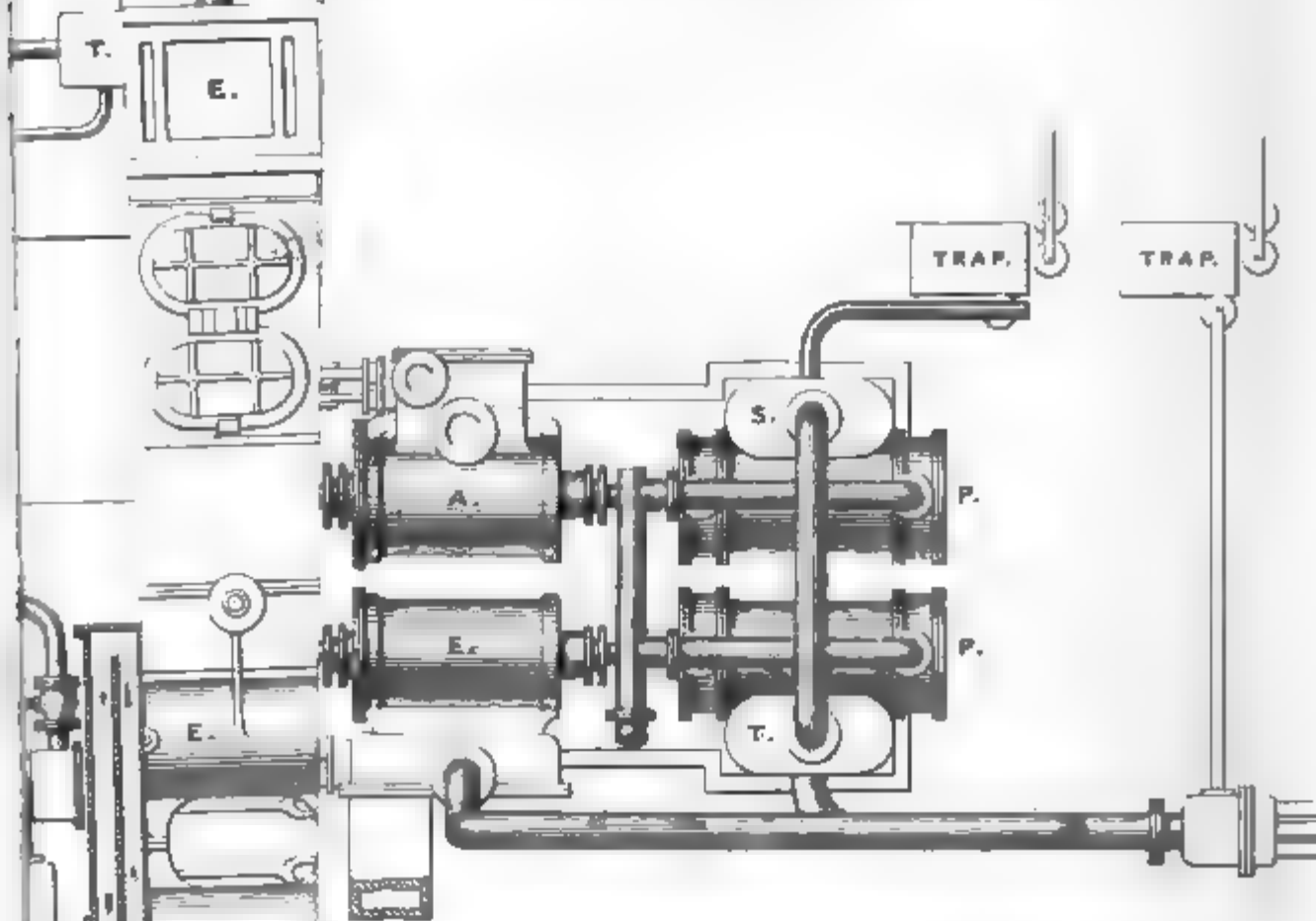


ERY.

: 6.



*It the position of the moisture depositing pipe and the lead of the
need so that the currents of air may be clearly shown and depth
arrangements actually adopted in practice which were with each ship.*



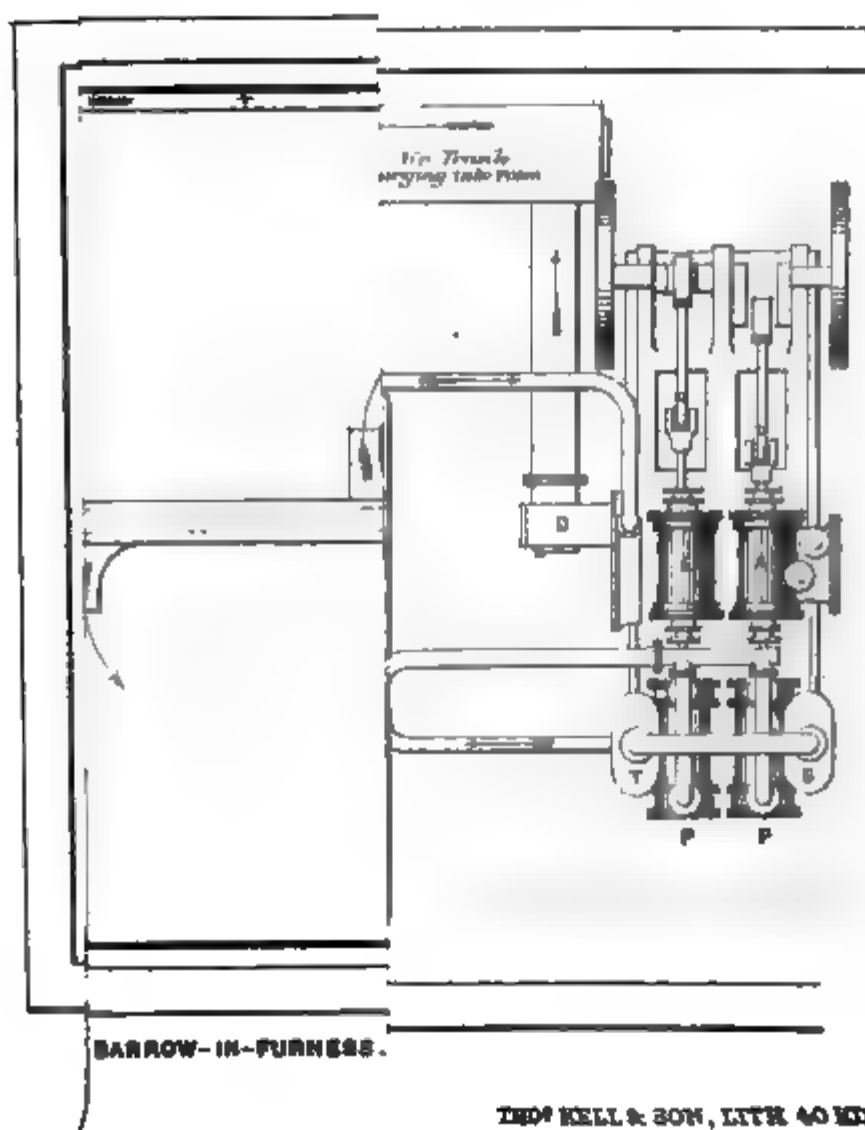
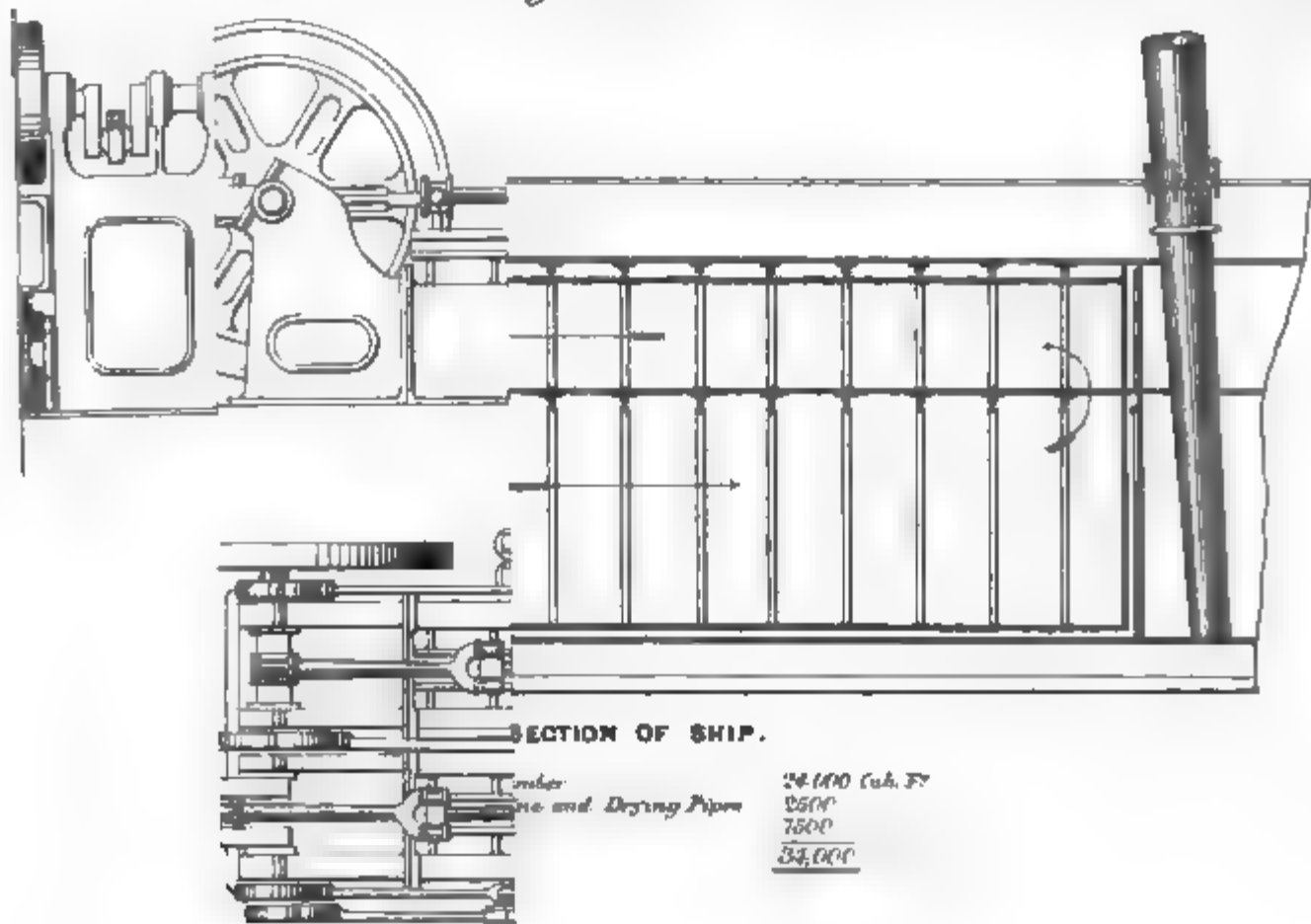
Scale for Fig^s 1, 2, and 6, 1/8 inch = 1 foot

45 Feet

Scale of


Fig. 11

Fig. 12.



Y.

PLATE 3.



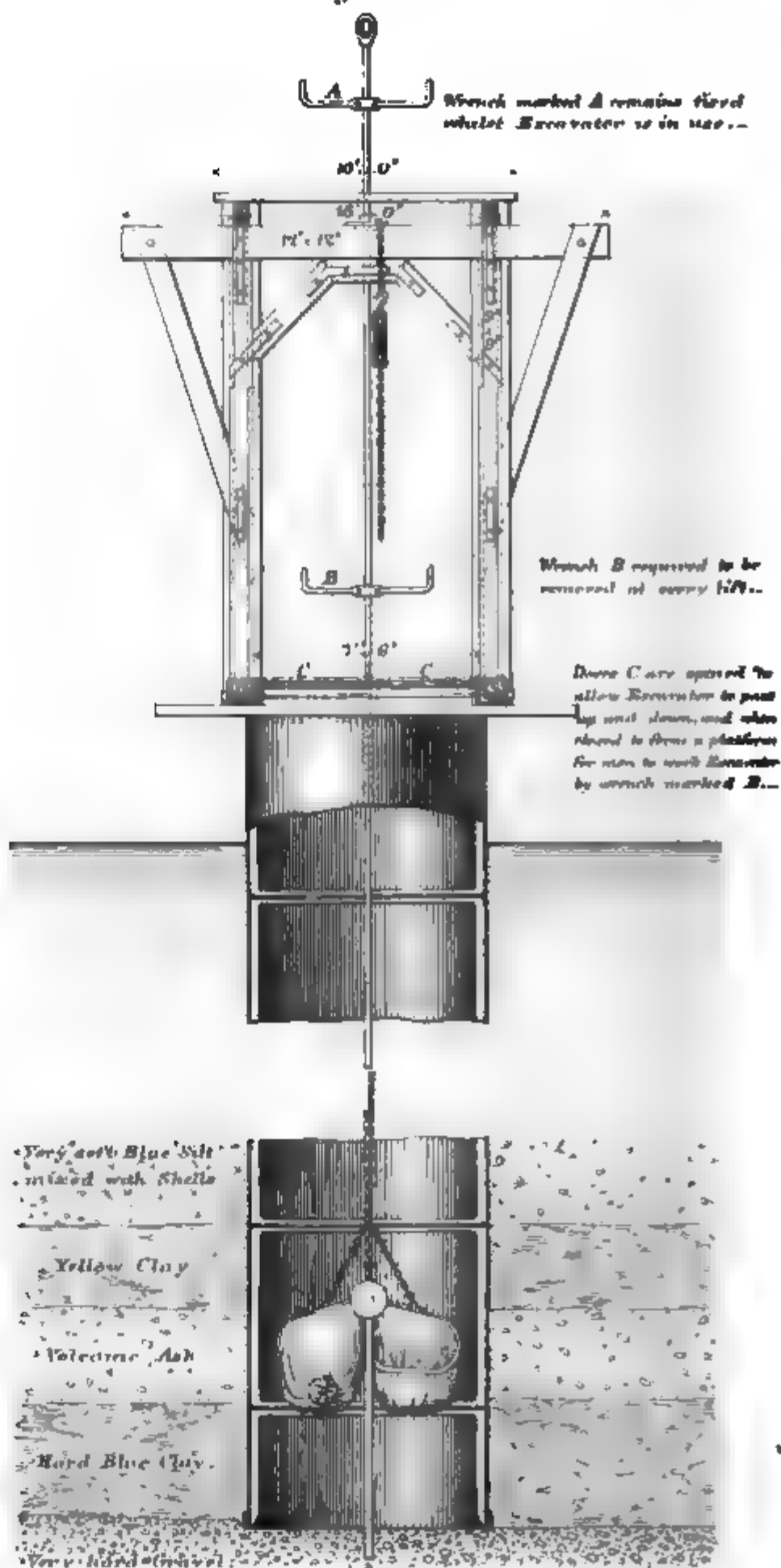
<i>Fig.</i>	<i>Diameter.</i> <i>Inches.</i>	<i>Mean</i> <i>Pressure</i>	<i>I.H.P.</i>	<i>Revolutions.</i>	<i>Stroke.</i> <i>Feet.</i>	<i>Scale of</i> <i>Curve.</i>
13	21	36.1	84.8	56	2	$\frac{1}{24}$
14	21	25.5	^(peak) 59.7	56	2	$\frac{1}{24}$
15	21	23.2	54.6	56	2	$\frac{1}{24}$
16	21	29	73.2	60	2	$\frac{1}{24}$
17	21	23.5	^(peak) 63.2	60	2	$\frac{1}{24}$
18	21	24.4	61.4	60	2	$\frac{1}{24}$
19	21	28.7	72.3	60	2	$\frac{1}{24}$
20	21	22.95	^(peak) 57.8	60	2	$\frac{1}{24}$
21	21	21.95	55.29	60	2	$\frac{1}{24}$
22	17	35.4	88	70	2	$\frac{1}{32}$
23	23	25.9	91.3	70	2	$\frac{1}{32}$
24	17	21.9	42	70	2	$\frac{1}{32}$

BRIDGE.

EXCAVATOR.

PLATE. 4.

Fig : 5.



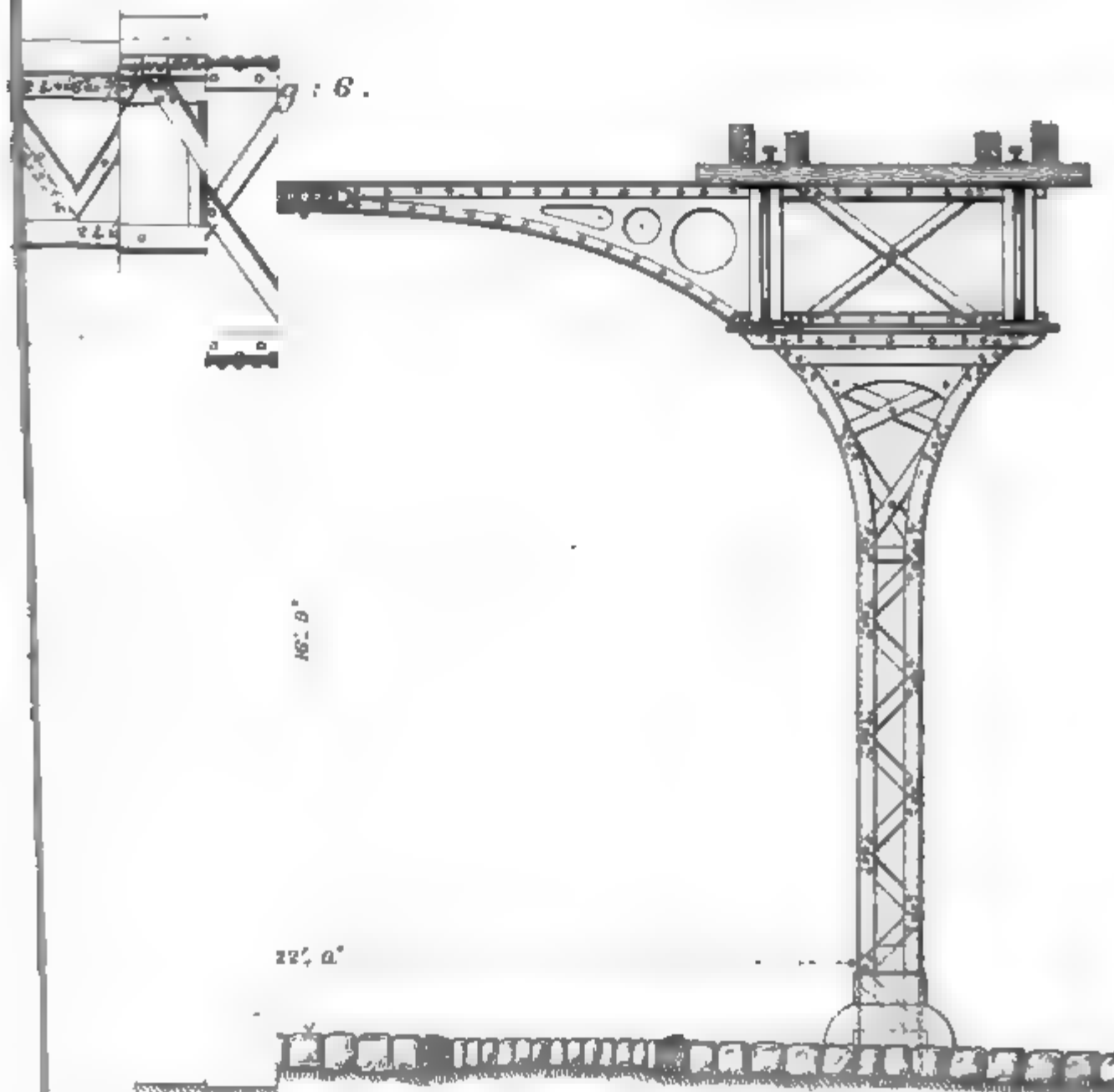
ELEVATION AND PLAN OF STAGING.

the Top of Cylinders, as need for working the Excavator.

Scale, 1/2 Inch = 1 Foot.

1 2 3 4 5 6 7 8 9 10 Feet.

Fl.



16' 0"

22' 0"

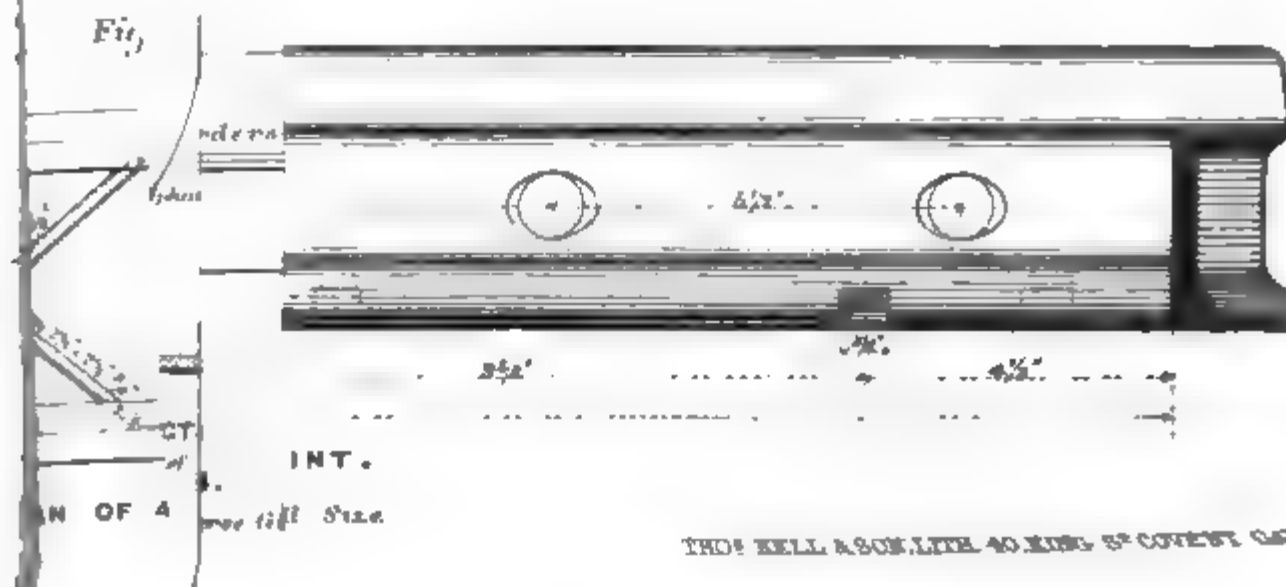
ELEVATION OF RAILROAD.

FEET

2 3 4

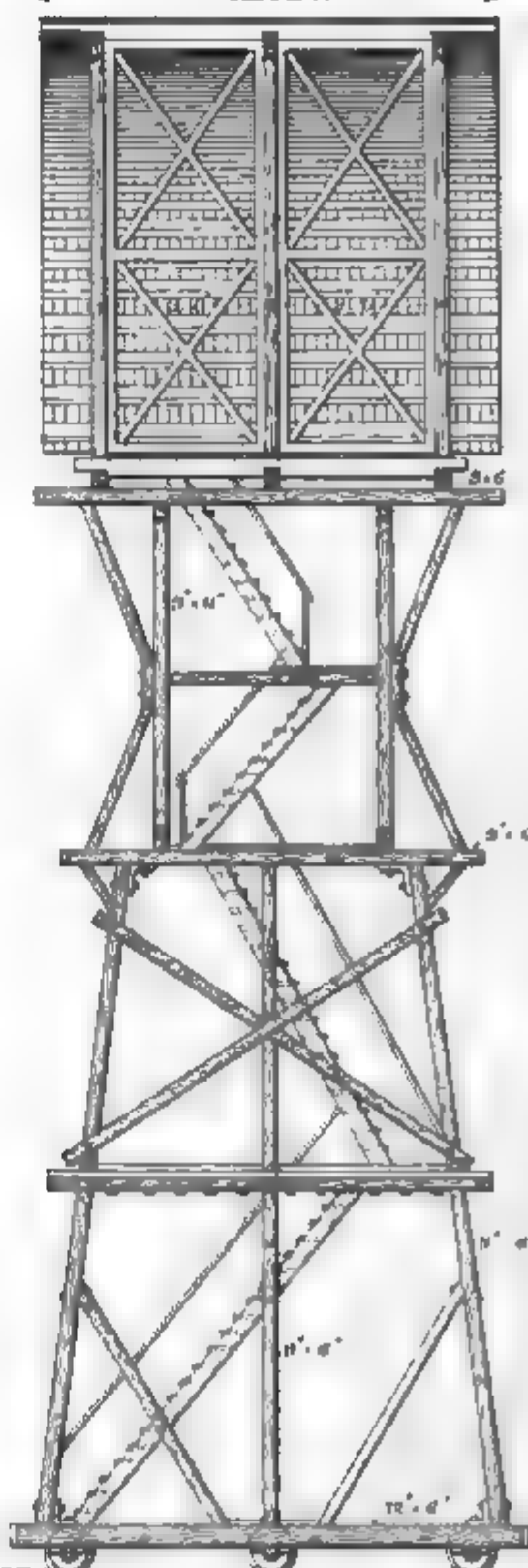
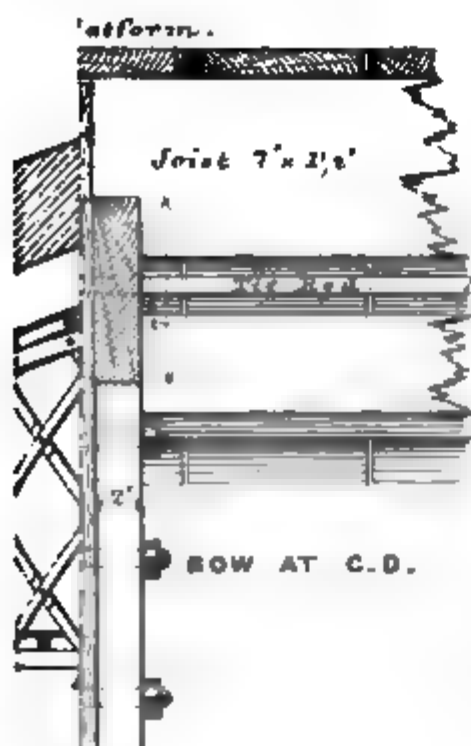
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Fig.

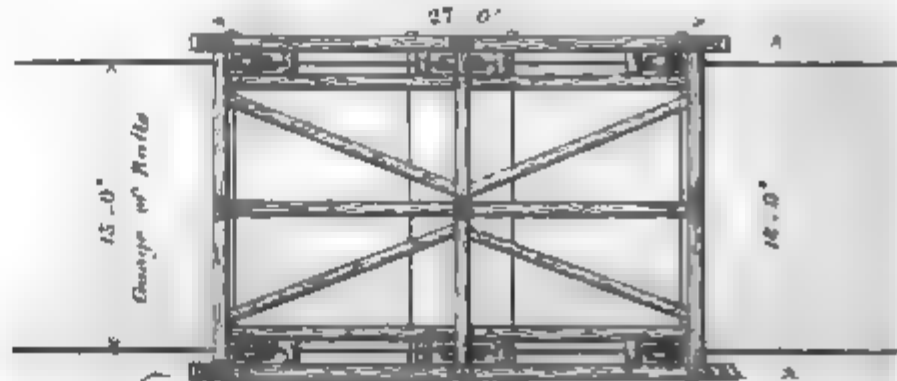


INT.

AN OF A



CROSS SECTION



PLAN OF UNDERFRAME.

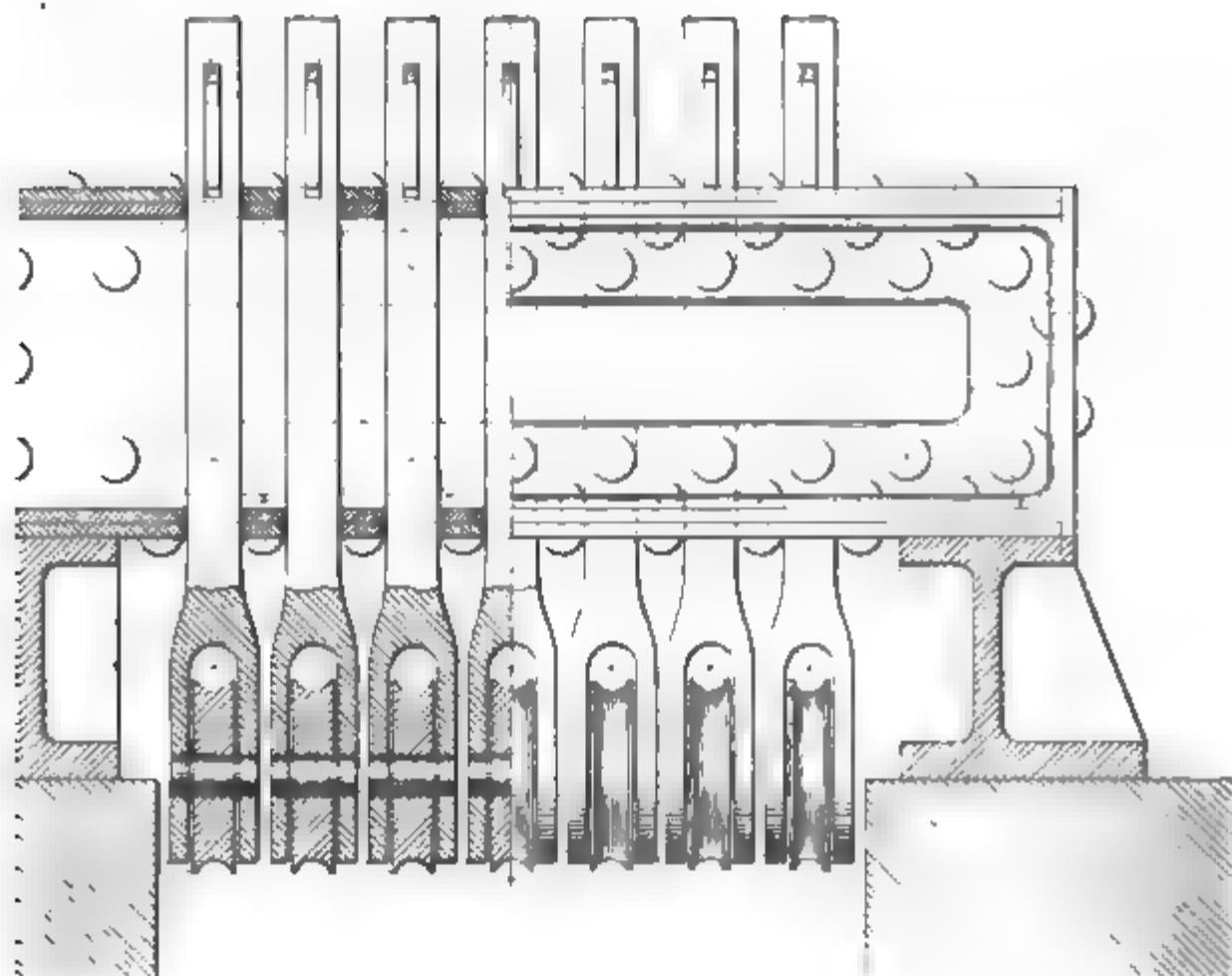
Fig 7

PLATE 7

Fig 7.

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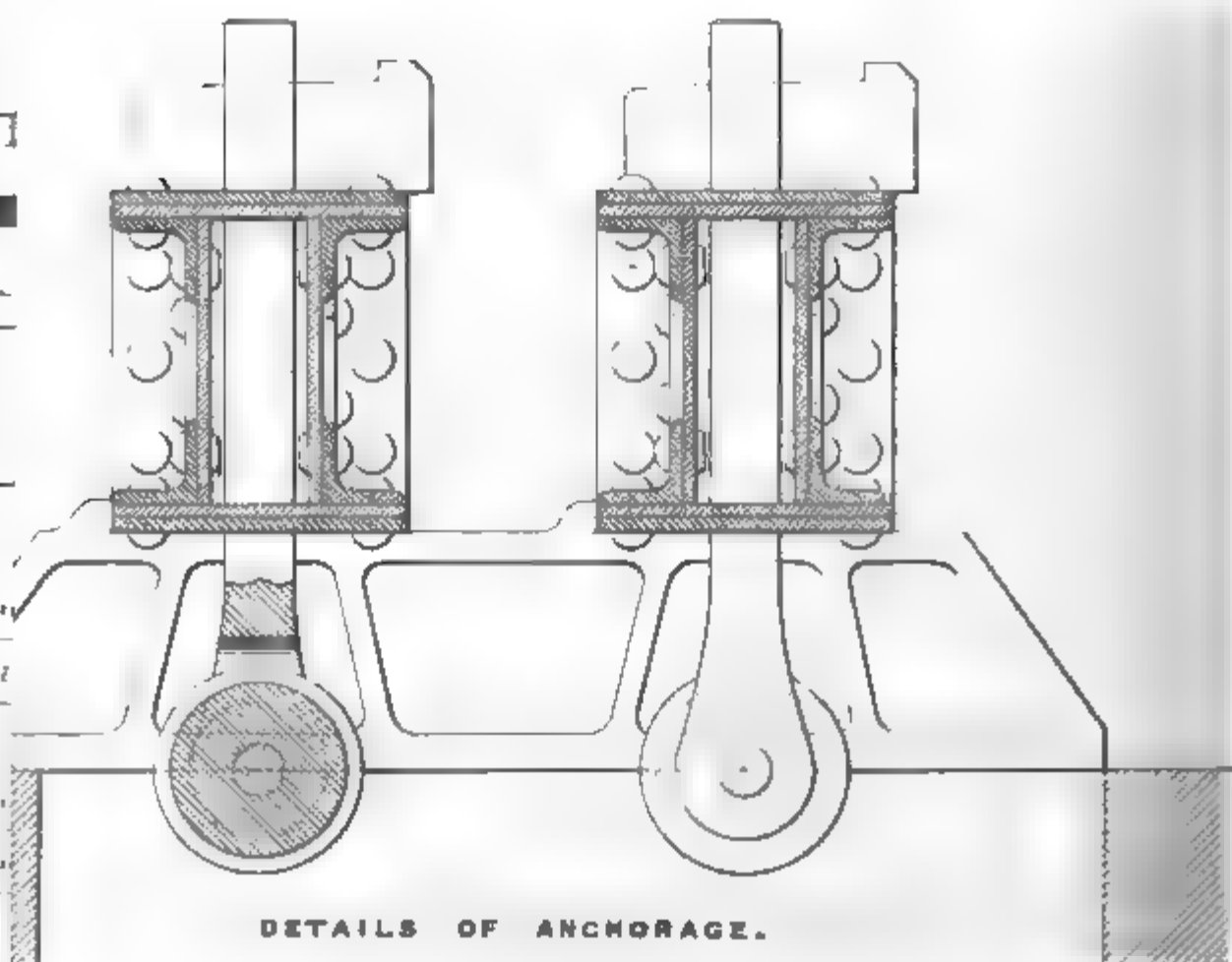
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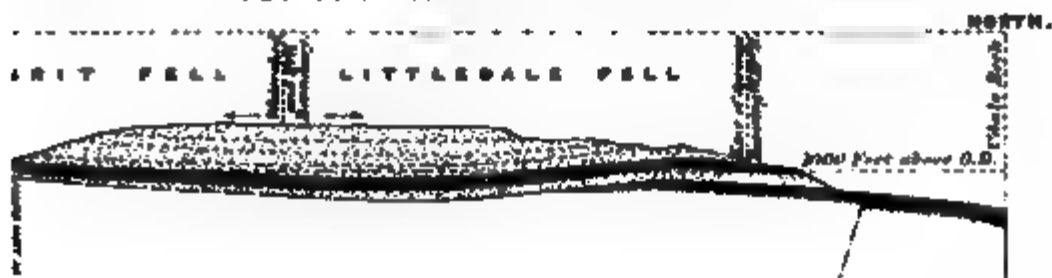
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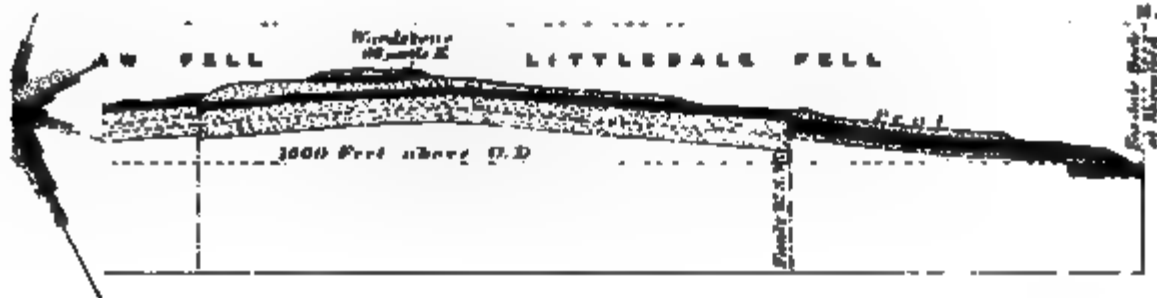


DETAILS OF ANCHORAGE.

SECTION A.



SECTION B.



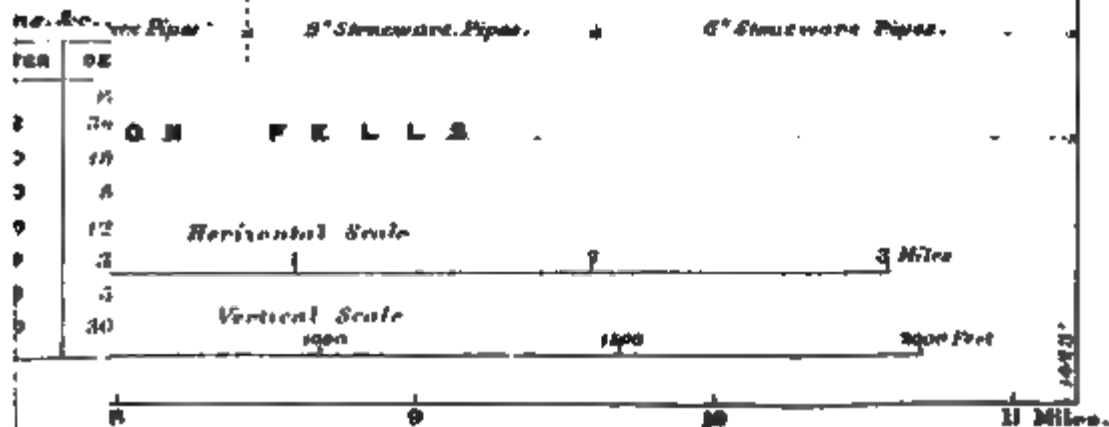
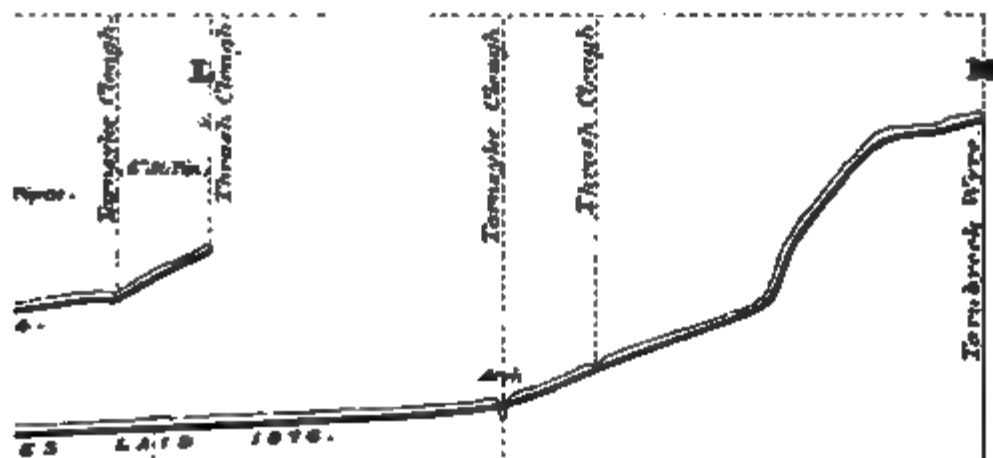
SECTION C.

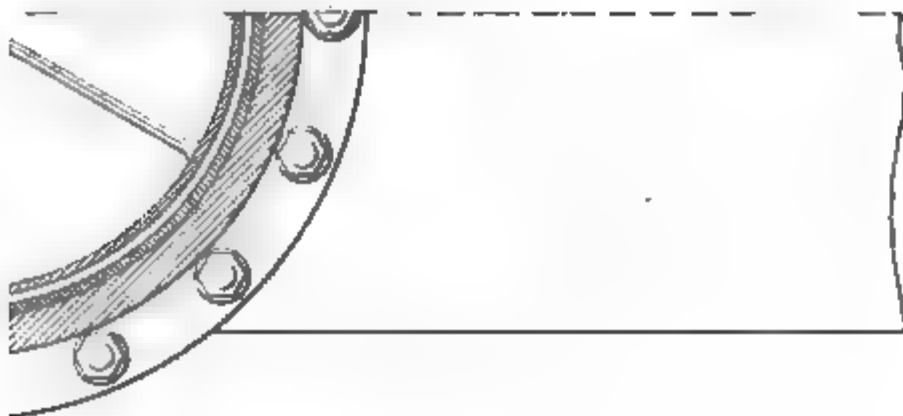


GEOLOGICAL SECTIONS.

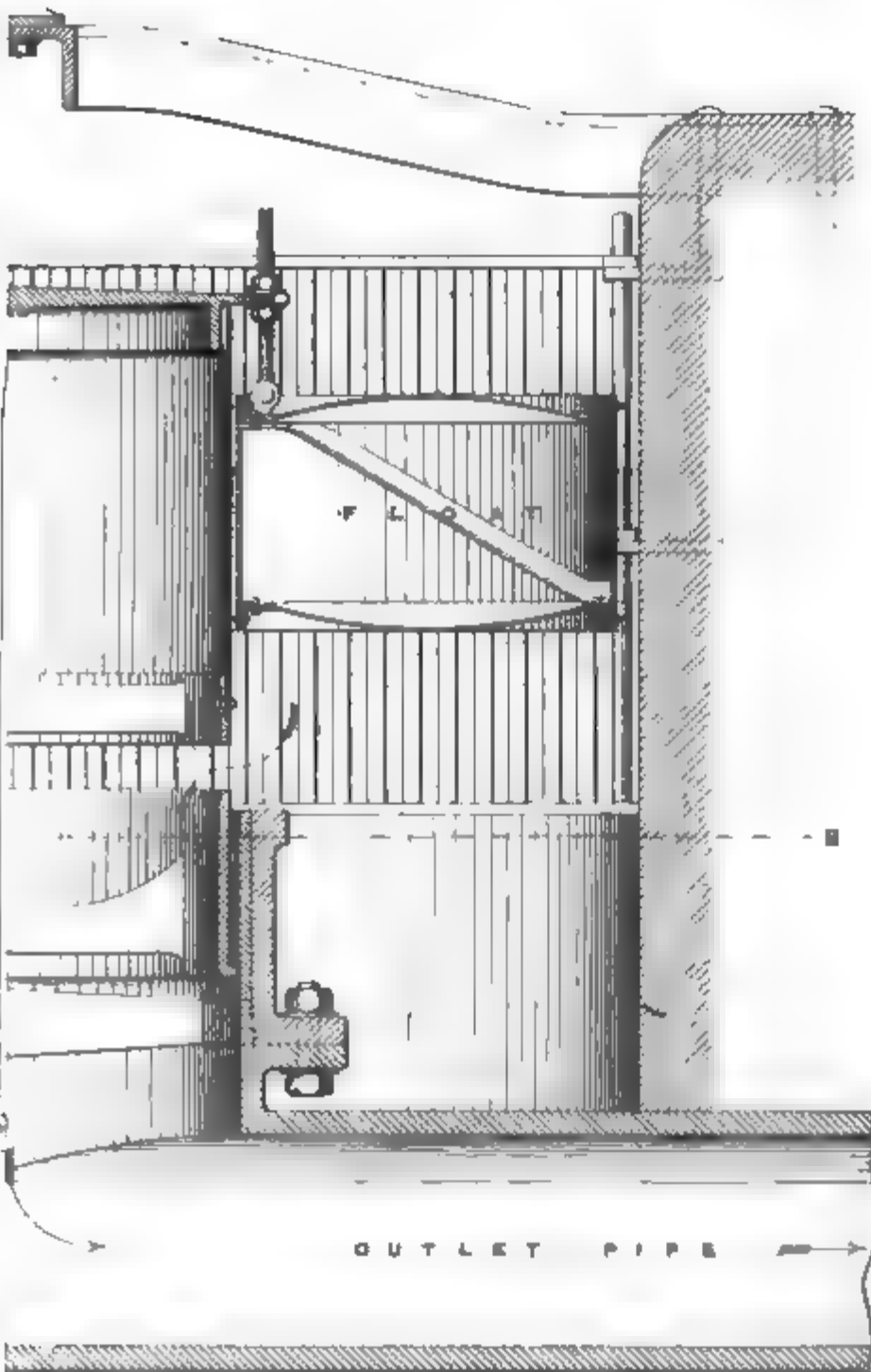
Scale for Geological Sections.

2000 3000 4000 5000 6000 7000 8000 9000 Feet.



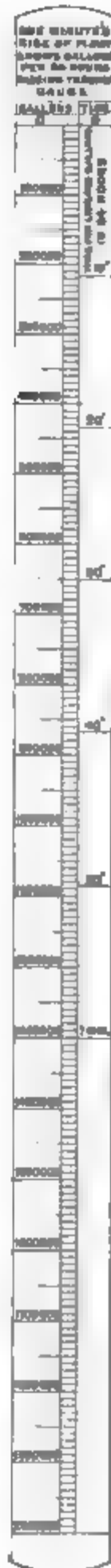


AT A.B.

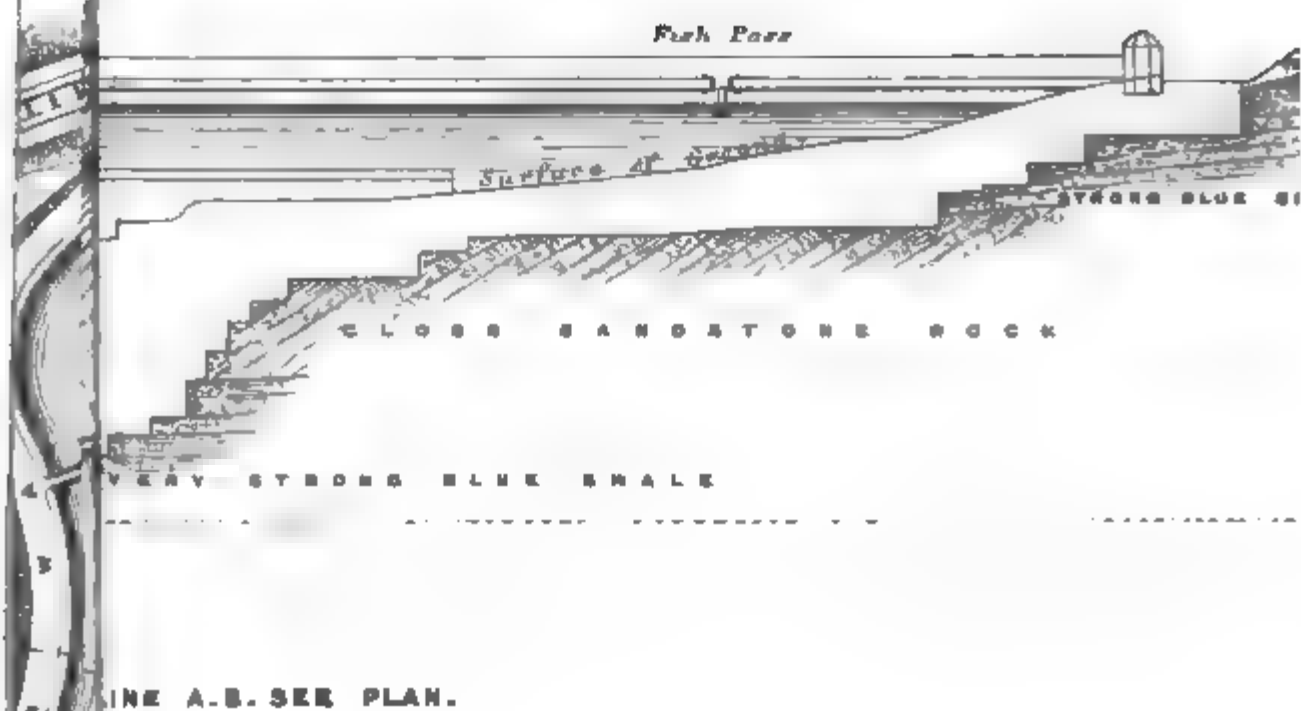


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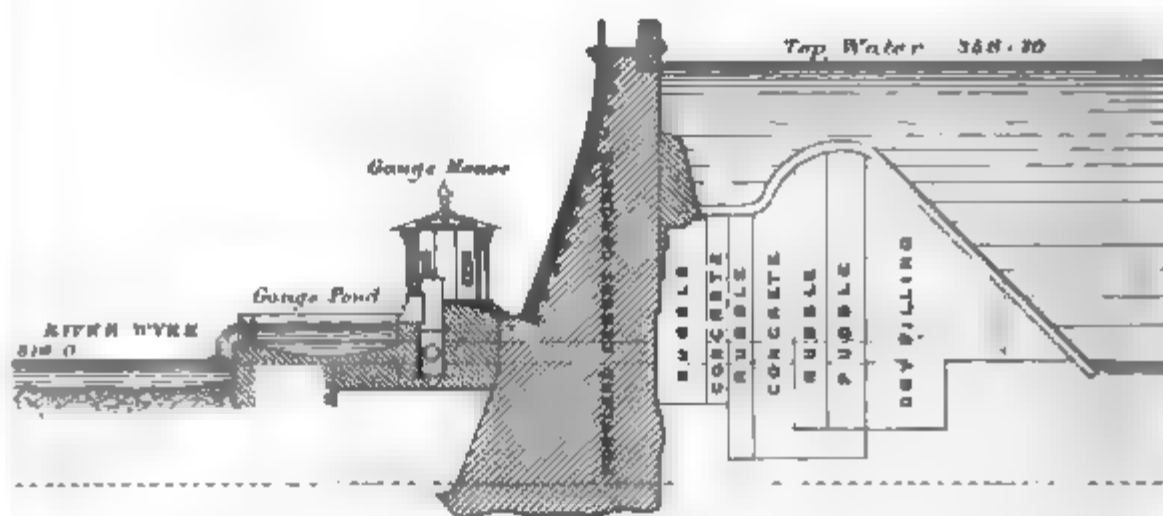
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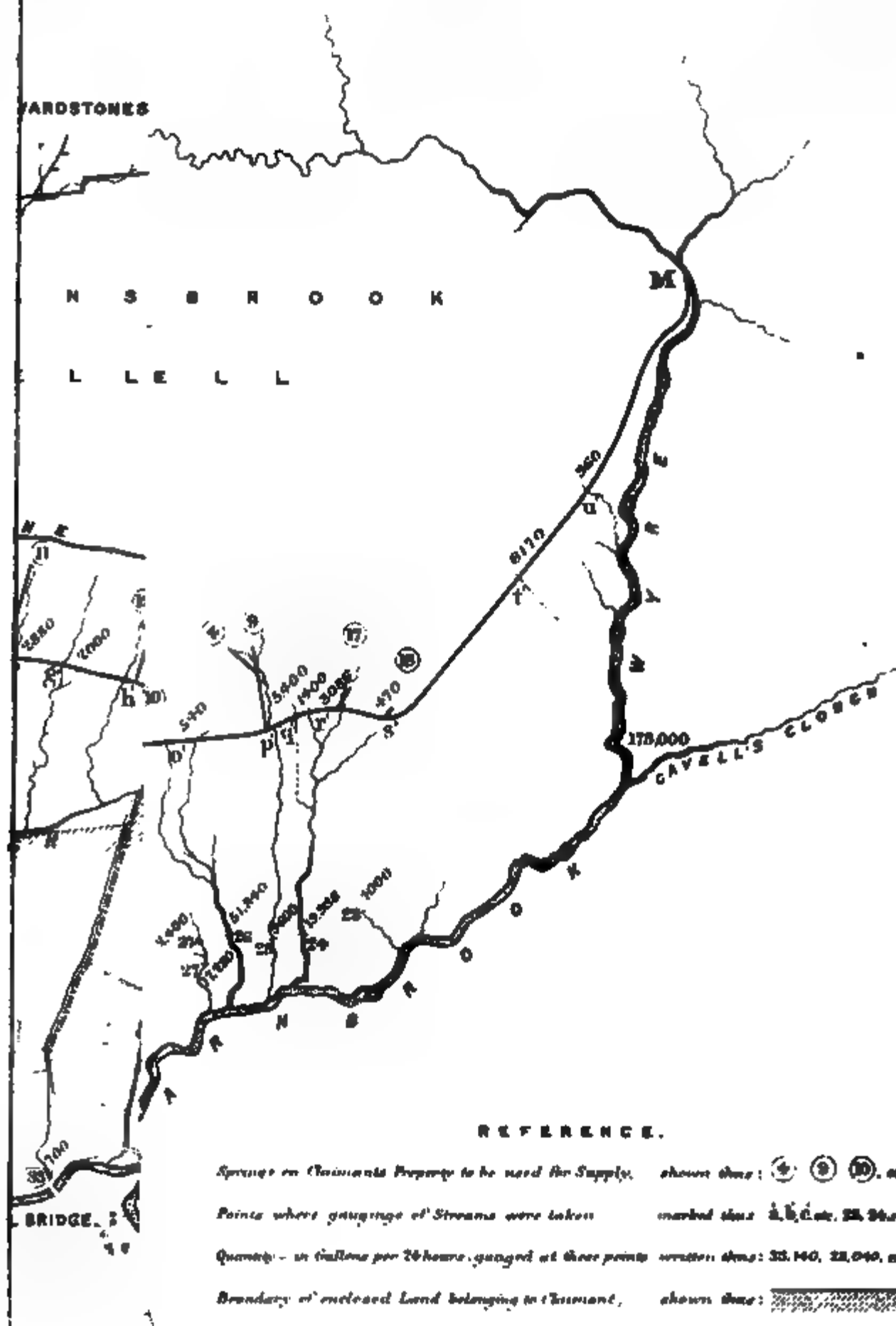
SCALE PLATE,
on First Bed in measuring chamber.



LINE A-B. SEE PLAN.



TRANSVERSE SECTION OF GAUGE HOUSE, MAIN WALL, &c. ON LINE E.F.



2 1/2 Miles



